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Carbon Monoxide Concentrations in Four U.S. Cities during the Winter of 1981

(U.S.) Environmental Monitoring Systems Lab.
Research Triangle Park, NC

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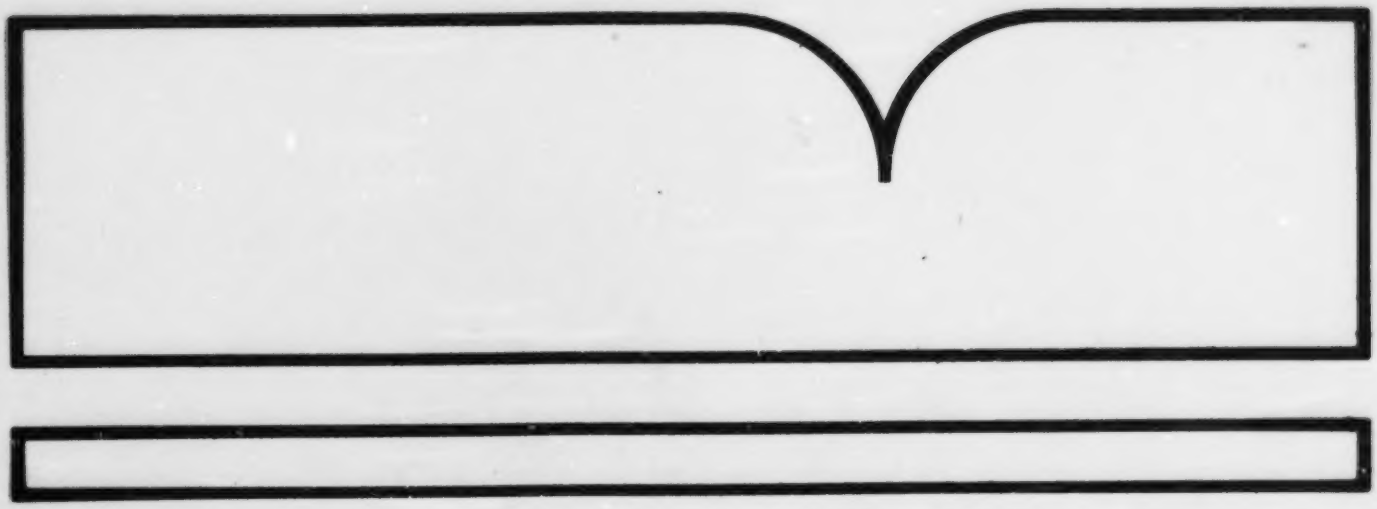

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June 1983

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CARBON MONOXIDE CONCENTRATIONS IN FOUR U.S. CITIES DURING THE WINTER OF 1981

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OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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16. ABSTRACT

Portable monitors were used to measure time averaged personal exposures (10-30 min) to carbon monoxide. Data were collected from January through March 1981 in four cities where carbon monoxide ambient levels in excess of National Ambient Air Quality Standards have been reported: Stamford, CT; Los Angeles, CA; Phoenix, AZ; and Denver, CO. In each city, personal exposures were measured in three typical microenvironment types: "indoor," "commuting," and "residential driving." These measurements were made in the vicinities of fixed monitoring stations that recorded ambient levels of carbon monoxide. This study design permitted the subsequent comparison of simultaneous personal exposures and ambient concentrations.

The highest indoor personal exposures were recorded in Denver (arithmetic mean value of 6.1 ppm). The highest commuting (11.4 ppm) and residential driving (7.6 ppm) exposures were recorded in Los Angeles. Except in Stamford, personal exposures were higher than fixed-site ambient concentrations during commuting and residential driving activities. Indoor exposures were lower than fixed-site concentrations in all cities except Denver.

For all cities, the linear relationships between simultaneous fixed-site and personal exposure measurements were found to be very poor. Any relationship that may exist between these two types of measurements is probably very complex. The exposure vs. fixed-site linear relationships were further complicated in this study by the large distances separating many measurements of the personal exposures and fixed-site concentrations.

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FOREWORD

Measurement and monitoring research efforts are designed to anticipate potential environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that impact health and the ecology, to provide innovative means of monitoring compliance with regulations, and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina, has the responsibility for: assessment of environmental monitoring technology and systems; implementation of Agency-wide quality assurance programs for air pollution measurement systems; and supplying technical support to other groups in the Agency including the Office of Air, Noise, and Radiation, the Office of Toxic Substances, and the Office of Enforcement.

Human exposures to carbon monoxide depend upon highly variable activity patterns. For example, the exposure in a residence, an occupational setting, or a motor vehicle may be significantly different from the monitored ambient level. Accordingly, this study was designed to collect simultaneous ambient and personal exposure data in microenvironments where such differences are expected to occur. The results of the CO monitoring during this study are summarized in the report.

Thomas R. Hauser
Director
Environmental Monitoring Systems Laboratory
Research Triangle Park, North Carolina

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ABSTRACT

Portable monitors were used to measure time averaged personal exposures (10 to 30 min) to carbon monoxide. Data were collected from January through March 1981 in four cities where carbon monoxide ambient levels in excess of National Ambient Air Quality Standards have been reported: Stamford, CT; Los Angeles, CA; Phoenix, AZ; and Denver, CO. In each city, personal exposures were measured in three typical microenvironment types: indoor, commuting, and residential driving. These measurements were made in the vicinities of fixed monitoring stations that recorded ambient levels of carbon monoxide.

The highest indoor personal exposures were recorded in Denver (arithmetic mean value of 6.1 ppm). The highest commuting and residential driving exposures were recorded in Los Angeles (11.4 ppm and 7.6 ppm, respectively). Except in Stamford, personal exposures during commuting and residential driving activities were higher than fixed-site ambient concentrations. Indoor exposures were lower than fixed-site concentrations in all cities except Denver.

For the four cities, the linear relationships between simultaneous fixed-site and personal exposure measurements were inconclusive. Any relationship that may exist between these two types of measurements is probably very complex. The exposure vs. fixed-site linear relationships were further complicated in this study by the large distances separating many measurements of the personal exposures and fixed-site concentrations.

Ambient concentrations were highest during the morning (7 to 8 a.m.) and evening (4 to 6 p.m.) hours, with average hourly peak levels of approximately 6 ppm. An exception to this pattern was observed in Stamford where average levels of 10 to 12 ppm were recorded at one fixed site.

This report covers a period from January to March 1981, and work was completed as of December 1981.

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This report was compiled by David M. Holland (EMSL/RTP) from various contractor reports and results of the statistical analyses. Gerald G. Akland (EMSL/RTP) provided oversight and guidance during the preparation of this report. David T. Mage, as Project Officer, (EMSL/RTP) prepared general instructions that formed the basis for the monitoring procedures used by the contractor personnel in each city. Terence Fitz-Simons (EMSL/RTP) and Susan Casada (EMSL/RTP) provided support in programming the statistical analyses and graphic material that appear in the report. Ronald Drago (EMSL/RTP) participated in the field surveys and instrumentation.

The efforts of the many state and local workers who assisted in providing fixed site ambient data during this study should also be acknowledged.

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SECTION 1

INTRODUCTION

Ambient levels of carbon monoxide (CO) are regulated according to the National Ambient Air Quality Standards (NAAQS). The Office of Mobile Sources is responsible for regulating motor vehicle emissions -- the major source of CO in the urban enviroment. When the NAAQS for CO are violated, the states involved must effect State Implementation Plans (SIPs) to reduce the ambient levels to meet the NAAQS. The fundamental premise is that when a CO standard is violated at an urban monitoring station, the people in the area surrounding the station also are exposed to CO levels above the NAAQS; therefore, a SIP is necessary. However, actual human CO exposures in various indoor and outdoor activity patterns are affected by highly localized phenomena and may be significantly different from ambient CO levels recorded at fixed stations that are sparsely distributed in urban areas. These phenomena include vehicle emissions, smoking, and indoor ventilation conditions. Accordingly, the "CO Winter Studies" were designed to collect personal CO exposures in microenvironments located in the vicinity of fixed monitoring stations. The data from the two types of measurements were compared to determine if individuals were exposed to the CO levels indicated by the fixed monitoring station. For the purposes of this study, microenvironments are defined to be specific locations with air space of homogeneous CO concentration. Microenvironment types are groups of similar microenvironments. These terms are detailed further in a report by Duan (1982).

The study was conducted during an 8-wk period in the winter (January to March) of 1981 in four U.S. cities where ambient CO levels above the NAAQS had been previously observed. The following contractors performed the monitoring of this study:

City	Contractor	Contract Number
Stamford	GCA Corp., Technology Div.	68-02-3168
Los Angeles	Science Applications, Inc.	68-02-3412
Phoenix	Systems, Science and Software, Inc.	68-02-3629
Denver	PEDCo Environmental, Inc.	68-02-3173

Stamford was selected because of the high occurrence of CO fixed-site measurements in excess of the 8-h NAAQS standard of 9 ppm, which are due to the monitor's location near a busy intersection. Los Angeles was chosen because the average commute time is greater than the national average of about 20 min. Also, a 9-person pilot study using personal exposure monitors previously

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had been conducted in Los Angeles. Phoenix was chosen because, unlike most cities, the highest CO ambient levels are measured during the evening hours. This may be a result of evening atmospheric inversions that occur before the evening rush hour traffic period. Thus, evening CO levels may be high in Phoenix even if vehicle emission levels decrease after the evening rush hour traffic. Denver was selected because of its high elevation above sea level. At Denver's altitude, more automobile exhaust may be released into the air due to inadequate adjustment of vehicle engines to the lower levels of oxygen available for fuel combustion.

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SECTION 2

STUDY DESIGN

MICROENVIRONMENT MONITORING

The data collection plans described below were designed to simulate time-averaged personal CO exposures (ppm per minute) in each of three typical microenvironment types ("indoor," "commuting," and "residential driving") in each city. The monitoring activities of this study should be regarded as microenvironment monitoring and not as personal monitoring. With personal monitoring, human subjects are sampled from the general population and the subjects record CO exposures in microenvironments according to their activity patterns. With microenvironment monitoring, microenvironments are sampled from a frame of relevant microenvironments. Thus, when microenvironment data are analyzed, an implicit assumption of equal visit frequency to each microenvironment is imposed because the activity patterns of human subjects are not recorded.

Indoor

One of the contractor personnel measured CO in locations immediately surrounding a fixed monitoring station by carrying a personal monitor into restaurants, shops, offices, and public buildings. This approach treats the person as a receptor and measures the CO levels that actually come into contact with the person. At each location, average CO concentrations were collected for 10-30 min time periods. A standard route was followed; the exact choice of locations depended on the local building types, distances, and permissions obtained.

Commuting

Two contractor personnel drove back and forth along the major commute routes to and from the urban area containing a fixed monitoring station between 7 and 9 a.m. and 4 and 6 p.m. The routes were chosen to constitute approximately 30-min segments of driving in a constant direction. As a result of this monitoring schedule, each commute period resulted in eight 30-min average exposures (two drivers during each 2-h commute period) representative of the exposures of the commuters using these path segments to reach the area of the fixed monitoring station.

Residential Driving

The typically low CO levels found in residential areas not located in close proximity to major thoroughfares represent the exposures of significant

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numbers of people. The air inside a vehicle traveling on residential streets of low traffic density is considered to be representative of the ambient air. One of the two contractor personnel performed such monitoring on lightly traveled roads in areas farther than one mile from the fixed monitoring station. Data were obtained from inside vehicles traveling at an average speed of 30 mi/h. CO average concentrations were collected at 10-min intervals during 30-min sampling periods corresponding to 15-mi driving segments. Data were collected during morning and afternoon hours.

FIXED-SITE MONITORING

Fixed-site CO concentrations were recorded at two downtown locations in Stamford and at ten locations in Los Angeles. In Phoenix, concentrations were determined at an urban and at an urban-residential site; in Denver, at an urban and at an urban-residential site. Detailed descriptions of these sites are given in Section 5 of this report.

DESIGN VARIATIONS

The study in each city was conducted by a different contractor and, as a result, there is some variation in study design from city to city. This is particularly true in the selection of indoor microenvironments and the length of the personal exposure averaging times within each city. Due to these design variations, certain statistical analyses vary from city to city. Detailed descriptions of the actual sampling designs implemented in each city are given in Section 5.

SECTION 3

QUALITY ASSURANCE

Table 1 delineates the quality assurance objectives for the measurement data. To verify that these objectives were being accomplished, the Research Triangle Institute conducted a system audit at each city.

TABLE 1. QUALITY ASSURANCE OBJECTIVES

Measurement Method	Experimental Conditions	Precision (standard deviation)	Accuracy	Completeness
Nondispersive infrared	Calibrate using certified synthetic atmospheres containing CO at 50% and 90% of instrument's full scale value and zero	∓10%	±10%	90%
Electrochemical		∓10%	±10%	90%

FIXED-SITE MONITORS

Eight fixed-site monitors (two at each city) were audited. Performance evaluations were based on estimates of the slope and intercept of the linear regression of the monitor response on the audit concentration. Five audit concentrations were used in these evaluations. "Excellent," "satisfactory," and "unsatisfactory" performance are defined in Table 2.

TABLE 2. PERFORMANCE DEFINITIONS

Performance level	Slope	Intercept
Excellent	∓5%	∓3% of full scale
Satisfactory	∓15%	∓3% of full scale
Unsatisfactory	>±15%	> ±3% of full scale

The complete audit results are presented in Appendix A. Briefly, six monitors gave excellent performance, one satisfactory performance and one unsatisfactory performance based on the performance definitions for the fixed site monitors. The one unsatisfactory fixed site monitor was located in Los Angeles. This monitor failed to meet the satisfactory performance level on the basis of its slope estimate of 0.80 (-20%). However, the data generated from this monitor were included in the study on the basis of its low precision and high completeness (>90%) level.

PERSONAL MONITORS

Nine General Electric personal CO monitors were audited. The complete audit results are shown in Appendix B. Briefly, four monitors gave excellent performance, three satisfactory performance, and two unsatisfactory performance. Even though the audit results indicated problems, the data from all instruments were included in the study.

Recalibration and cross-comparisons between instruments within a city continued throughout the study. As a result, 80% of the calibration readings were within ∓10% and 92% were within ∓13.3% of the low scale point (7.5 ppm). In addition, 85% were within 10% and 95% were within 15.5% of the upper scale point (35.5 ppm). The resulting accuracy for the population of all measurements was sufficient for the objectives of this study.

Data Validation

In cases of equipment failure, incorrectly recorded readings, or instrument drift of more than 14%, the CO values were omitted from the data analysis.

SECTION 4

RESULTS: COMPARISON OF PERSONAL EXPOSURE AND FIXED-SITE DATA AMONG CITIES

DESCRIPTIVE STATISTICS AND FREQUENCY HISTOGRAMS

Descriptive statistics were compiled for each microenvironment type (indoor, commuting, and residential driving) for each city. Table 3 lists statistics that provide a measure of the central tendencies of the data. The personal exposures within each microenvironment type were matched by time to the concentration recorded at the nearest fixed site in each city. Data that could not be matched by time were not considered in this analysis. For Stamford, summary statistics are provided for each of the two fixed sites. For Los Angeles, the personal exposures are matched to the nearest fixed site. For Phoenix, the indoor and commuting personal exposures are compared to data from the urban fixed site; the residential driving exposures are compared to the urban-residential fixed site. Denver data are matched similarly. (The various fixed sites are described in Section 5 of this report).

The majority of the personal exposures were not continuous in time. However, the fixed-site monitors usually recorded continuous 1-h averages. Thus, the summary statistics presented in Table 3 were obtained by comparing personal exposures that include only a portion of a given hour to hourly averages. This procedure introduces a fictitious replication into the analysis by repeating a given fixed hourly average for every personal exposure. Due to the large number of personal exposures in each microenvironment type (see sample sizes in Table 3), any possible effects of this replication should be negligible when comparing the arithmetic means of each type of measurement. However, it is important when comparing ranges, standard deviations, and frequency distributions that the time used in averaging be held constant since one expects to have more peaked looking distributions as the averaging time gets longer. This is partly due to the potential for CO concentrations to decrease or increase in relatively short time periods under conditions found in urban environments. Thus, the statistical results from comparing personal exposures that usually included only a portion of a given hour to hourly averages should be viewed with caution.

Figure 1 presents a bar chart of the arithmetic means shown in Table 3. Except for Stamford, each personal exposure arithmetic mean was higher than the corresponding fixed-site mean during commuting and residential driving. In addition, in Denver, the indoor mean was higher than the fixed-site mean. The arithmetic means and median values (Table 3) indicate that the highest indoor exposures were measured in Denver. As expected, the highest commuting and residential driving exposures were measured in Los Angeles. Stamford

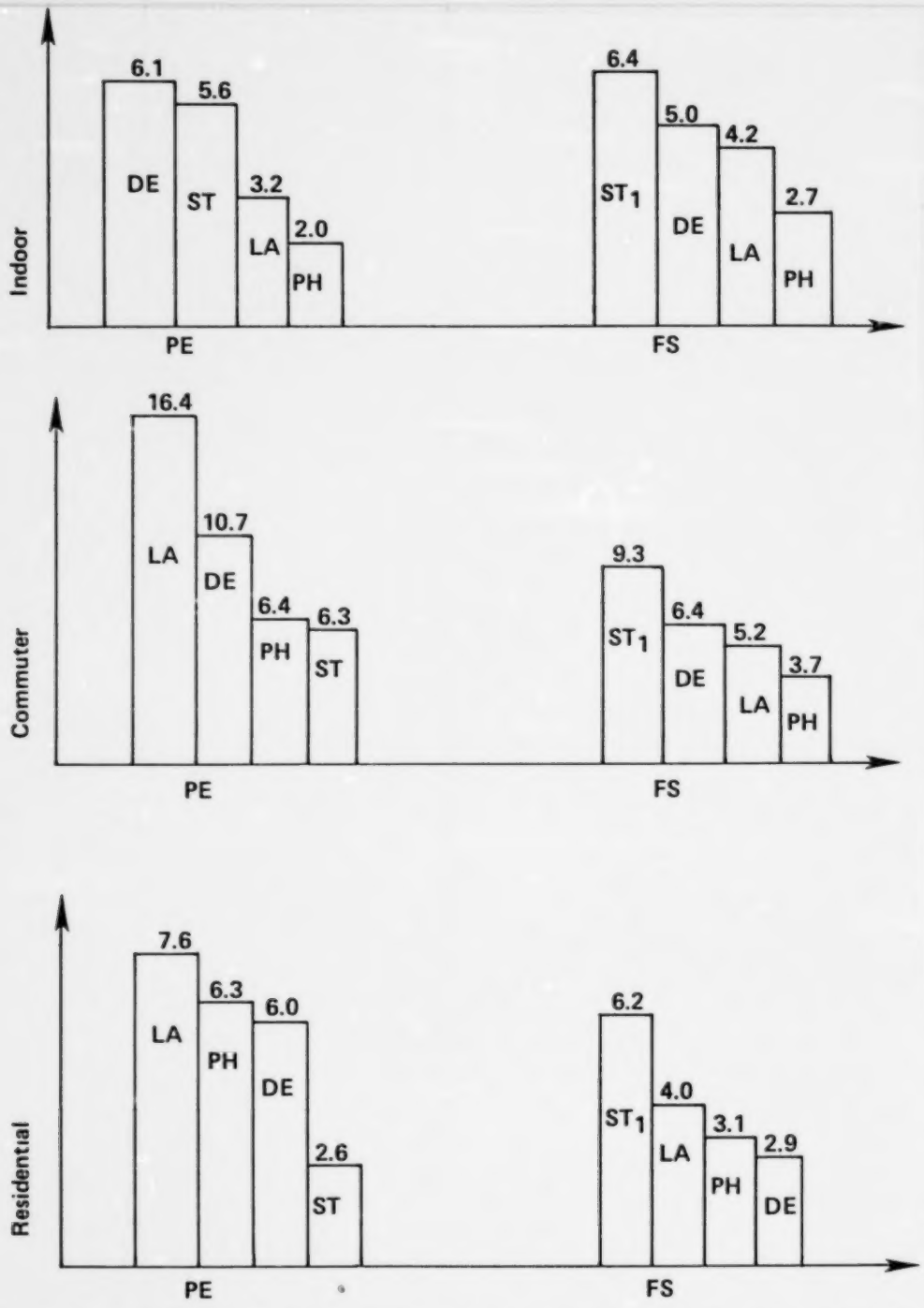


Figure 1. Bar chart of personal exposure and fixed-site arithmetic means (ppm) for each microenvironment. PE = personal exposure; FS = fixed site. ST = Stamford; LA = Los Angeles; PH = Phoenix; DE = Denver.

TABLE 3. SUMMARY STATISTICS: PERSONAL EXPOSURES AND FIXED-SITE CONCENTRATIONS BY MICROENVIRONMENT TYPE FOR FOUR U.S. CITIES

Microenvironment type	Statistic	Data source[a] Stamford[b] Personal Exposure	Stamford[b] Fixed Site 1	Stamford[b] Fixed Site 2	Los Angeles[c] Personal Exposure	Los Angeles[c] Fixed Site	Phoenix[d] Personal Exposure	Phoenix[d] Fixed Site	Denver[d] Personal Exposure	Denver[d] Fixed Site
Indoor	Sample size	659	659	659	1239	1239	380	380	1953	1953
	Geometric mean	3.0	5.0	1.3	2.3	3.3	0.3	1.6	4.2	4.2
	Arithmetic mean	5.6	6.4	2.0	3.2	4.2	2.0	2.7	6.1	5.0
	Standard deviation	8.0	3.8	2.2	2.5	3.2	2.2	2.5	4.8	3.3
	Median	2.7	6.8	1.0	2.6	3.0	1.5	2.0	5.0	4.0
	Range	0-61	0-25	0-12	0-18	1-21	0-17	0-13	0-58	1-24
	Correlation coefficient	0.14	0.03		0.47		0.48		0.33	
Commuting	Sample size	1341	1341	1341	96	96	839	839	3584	3584
	Geometric mean	4.9	6.6	1.8	15.2	4.0	4.7	2.6	7.9	5.5
	Arithmetic mean	6.3	9.3	2.8	16.4	5.2	6.4	3.7	10.7	6.4
	Standard deviation	4.7	5.7	2.9	6.2	4.0	4.7	3.0	7.6	3.9
	Median	5.2	9.6	1.9	15.5	4.0	5.3	2.5	9.0	5.7
	Range	0-38	0-25	0-16	3-42	1-21	0-50	0-16	0-55	1-27
	Correlation coefficient	0.12	0.27		-0.06		0.47		0.24	
Residential driving	Sample size	577	577	577	807	807	58	58	526	526
	Geometric mean	1.8	4.9	1.3	6.2	3.1	5.3	1.1	4.2	2.0
	Arithmetic mean	2.6	6.2	2.0	7.6	4.0	6.3	3.1	6.0	2.9
	Standard deviation	2.9	3.8	2.0	5.0	2.9	3.1	2.4	5.1	2.2
	Median	2.0	6.3	1.0	7.0	3.0	6.4	3.6	4.5	2.4
	Range	0-39	0-29	0-8	1-38	1-16	0-14	0-9	0-45	0-10
	Correlation coefficient	0.08	0.26		0.41		0.34		0.02	

[a]Averaging times of personal exposure and fixed data are not equal.
[b]Summary statistics are provided for each of the two fixed sites.
[c]Personal exposures are matched to the nearest fixed site.
[d]Indoor and commuting personal exposures are compared to data from the urban fixed site. Residential driving exposures are compared to the urban-residential fixed site.

fixed monitoring station 1, which was located near heavy construction activity, recorded the highest fixed-site concentrations.

The sample correlation coefficients, which provide an empirical measure of the linear association between the personal exposure and fixed-site measurements, are all very low (<0.5). The square of the correlation coefficient multiplied by 100 provides a percentage measure of the total sample variation that is accounted for in the linear relationship. For example, a correlation of 0.5 between two variables indicates that only 25% of the variation between the two variables is accounted for. As measured by the square of the correlation, none of the linear relationships are strong within any of the microenvironment types. Any relationship that may exist between these two types of measurements is probably very complex and cannot be adequately described by a simple linear relationship. The exposure vs. fixed site relationships were further complicated in this study by the large distances separating many of the personal exposures and fixed site concentrations.

Figures C1 to C-12 in Appendix C the histograms of the data presented in Table 3. For each city, the personal exposures are generally distributed with greater frequency at higher concentration levels than are the corresponding fixed-site concentrations. The concentrations recorded at monitoring station 2 in Stamford, however, do not follow the general trend. The commuting exposures in all four cities are skewed to the right and also occur with greater frequency at high concentration levels when compared to the fixed-site values. The indoor fixed and personal CO data are both highly skewed to the right. For each city, the indoor concentration interval containing the greatest number of measurements is 0.5 to 3.5 ppm.

HOURLY DIURNAL PATTERNS OF FIXED-SITE CONCENTRATIONS

Plots of the hourly fixed-site arithmetic means vs. hour of day (Figures 2 through 6) indicate that the highest CO concentrations occurred in the morning and evening hours. The morning peak occurred at approximately 8:00 a.m. and the evening peak varied from city to city. As expected, the evening peak occurred much later in Phoenix (around 10 p.m.). Also, the Phoenix evening peak concentration exceeded the morning peak, unlike the pattern observed in the other cities. Again, Stamford monitoring station 1 recorded the highest hourly mean concentrations. The morning and evening peak levels were approximately 6 ppm in the other three cities.

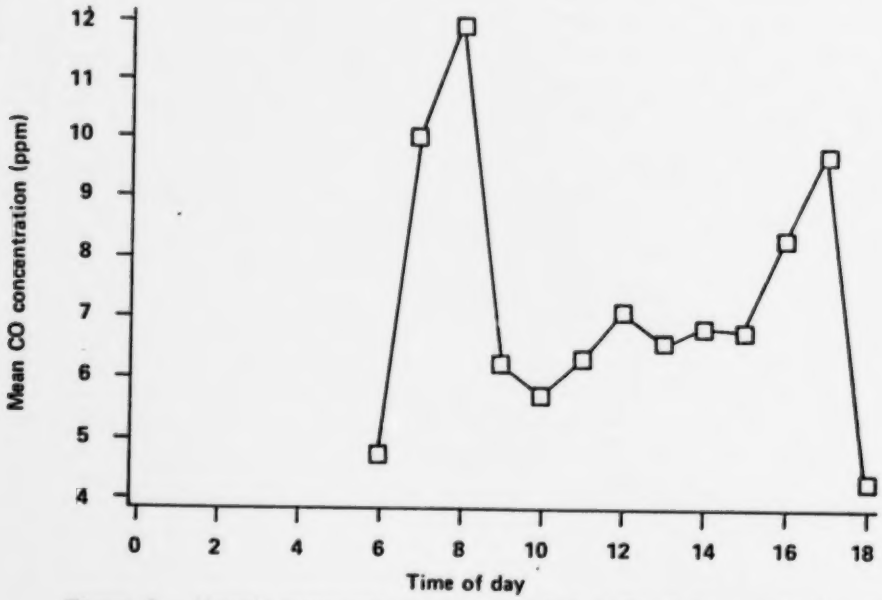


Figure 2. Hourly arithmetic means recorded at fixed-site monitoring station 1 located near a construction site and busy intersection in Stamford.

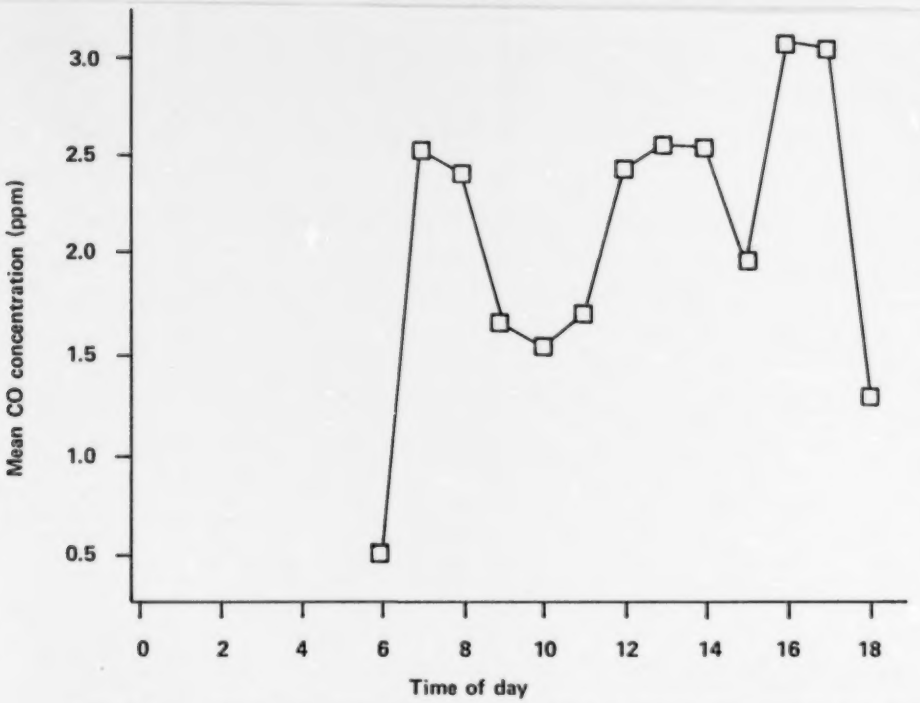


Figure 3. Hourly arithmetic means recorded at fixed-site monitoring station 2 located diagonally across the intersection from station 1 in Stamford.

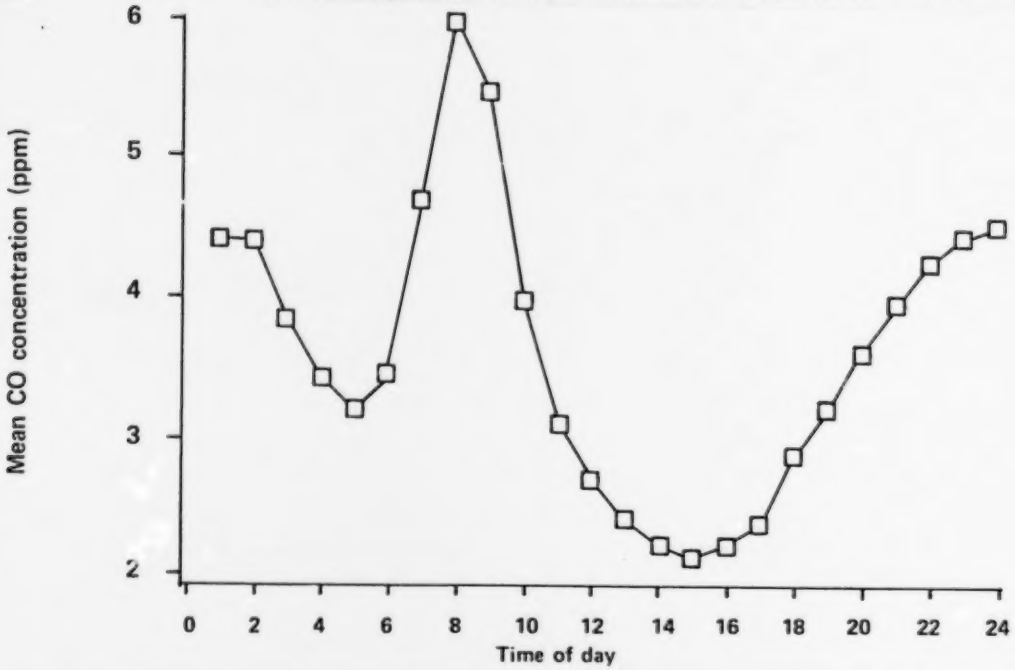


Figure 4. Hourly arithmetic means recorded at 10 fixed-site monitoring stations in Los Angeles.

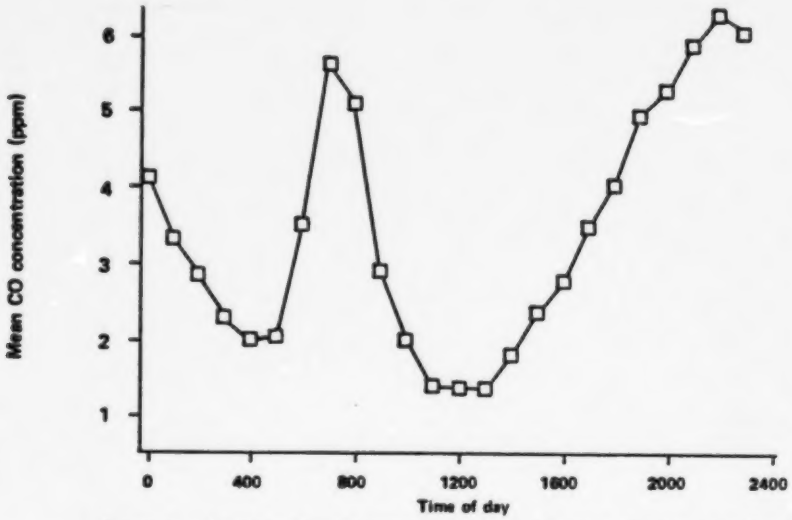


Figure 5. Hourly arithmetic means recorded at the urban fixed-site monitoring station in Phoenix.

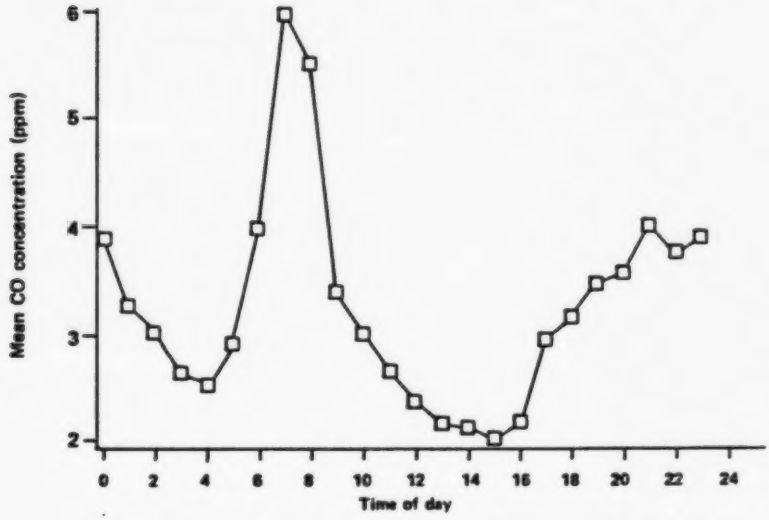


Figure 6. Hourly arithmetic means recorded at the urban-residential fixed-site monitoring station in Denver.

PERSONAL EXPOSURES DURING FIXED-SITE 8-HOUR NAAQS EXCEEDANCES

NAAQS exceedances (8-h average of more than 9 ppm) were recorded on 18 days at Stamford monitoring station 1. These exceedances occurred on 6 days

in February and 12 days in March. No 8-h exceedances were recorded at monitoring station 2 located diagonally across the street. At the 10 fixed sites in Los Angeles, 8-h exceedances were recorded on 30 days. At one site, 13 exceedance days were recorded. At the urban monitoring station in Phoenix, 8-h exceedances were recorded on 9 days. At the downtown station in Denver, 8-h exceedances were recorded on 18 days.

Figures 7 through 10 are histograms for each microenvironment type of the differences between personal exposures and fixed-site concentrations during 8-h exceedance time periods in each city. In Stamford, at least 84% of the concentrations recorded at station 1 were higher than the corresponding indoor, commuting, and residential driving personal exposures. The fact that no 8-h exceedances were recorded at station 2 (located diagonally across the intersection from fixed monitoring station 1) suggests that the concentrations recorded at station 1 were strongly influenced by the nearby traffic congestion and construction activity.

In Los Angeles, 85% of the fixed-site exceedance concentrations were higher than the indoor exposures. This result is consistent with the low indoor exposures found in all four cities. However, 75% of the residential driving exposures were higher than the fixed-site exceedance concentrations. Unfortunately, the limited commuter monitoring conducted during this study (12 days) coincided infrequently with exceedance days, and the histogram is based on only 3 values.

In Phoenix, 77% of the fixed-site exceedance values were greater than the simultaneous indoor exposures. Only 34% of the commuting exposures were greater than the fixed-site exceedance concentrations. This result is consistent with the lower commuting exposures in Phoenix (Table 1) in comparison to Los Angeles and Denver.

In Denver, over 50% of the fixed-site exceedance concentrations were greater than the indoor exposures. This result is somewhat surprising when one considers that, overall, the highest indoor exposures were found in Denver. However, over 50% of the commuting exposures and residential driving exposures were greater than the fixed-site exceedance values.

ESTIMATED EXPOSURE OF THE WINTER COMMUTING OFFICE WORKER

An indirect approach was used to estimate the exposure of a typical commuting-office worker. A time-weighted average exposure (equation 1) was calculated for the following activities: morning commute to office, work at office, midday eating and shopping, and evening commute to home. The time periods used to determine average estimates for each activity were 8-12 a.m. and 1-5 p.m. for work at the office, 7-9 a.m. for morning commute, and 4-6 p.m. for the evening commute. The midday hours used for the eating and shopping activities varied from city to city due to the different monitoring procedures used in each city. Although the morning and evening commute time periods overlap the assumed office hours, these times were used to provide a representative estimate of the average CO levels of these activities.

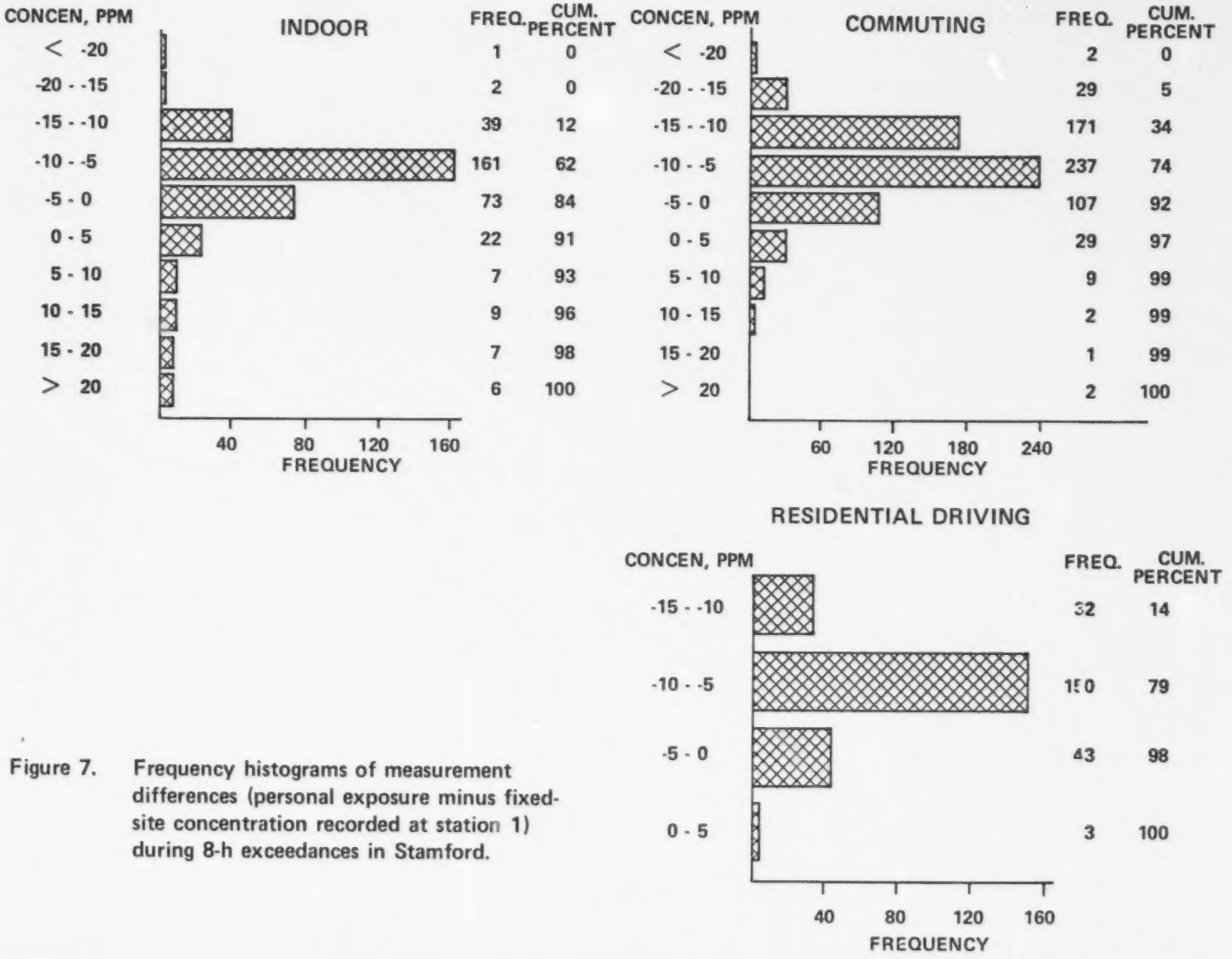
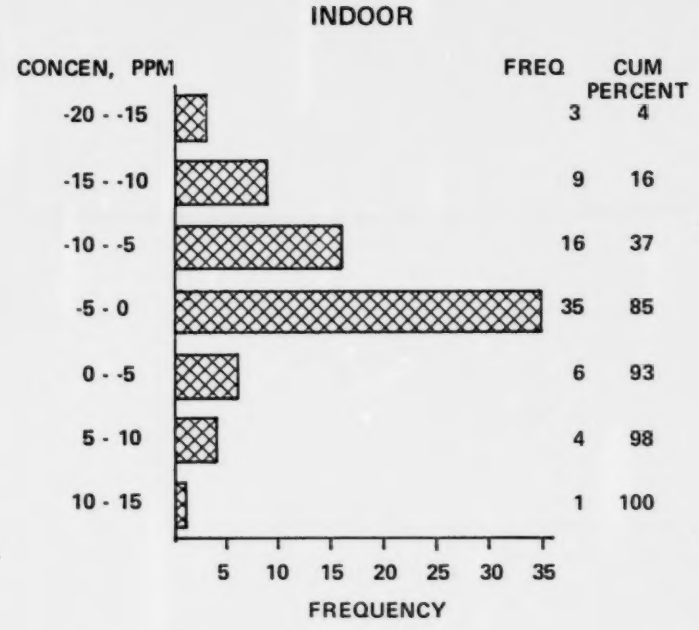
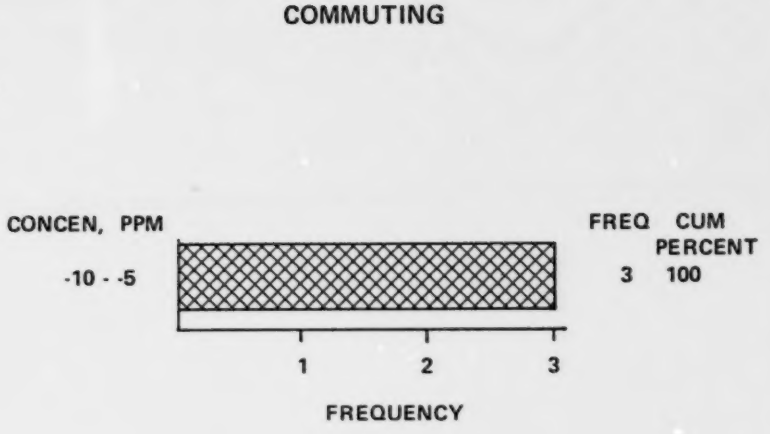


Figure 7. Frequency histograms of measurement differences (personal exposure minus fixed-site concentration recorded at station 1) during 8-h exceedances in Stamford.





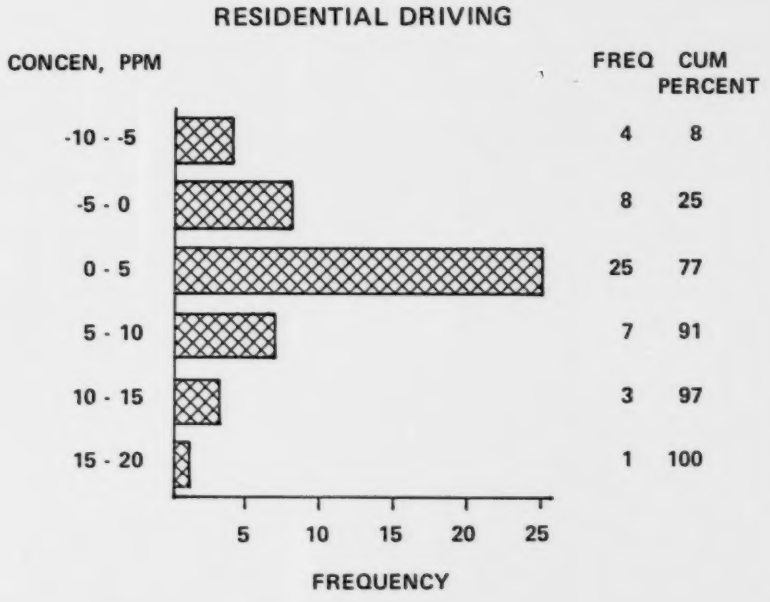
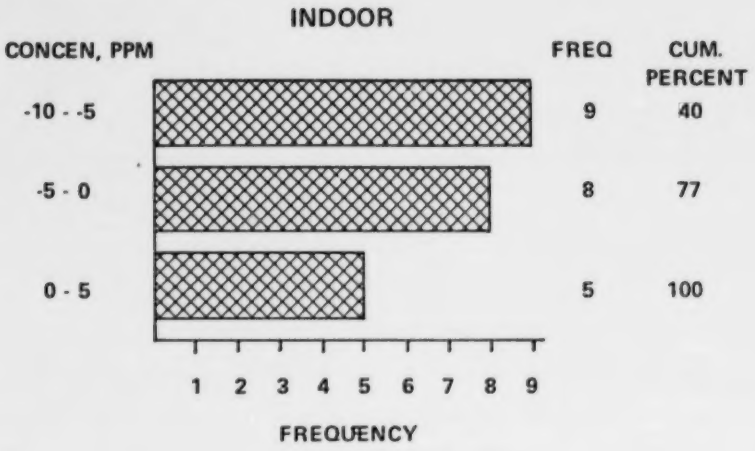


Figure 8. Frequency histograms of measurement differences (personal exposure minus fixed-site concentration) during 8-h exceedances in Los Angeles.



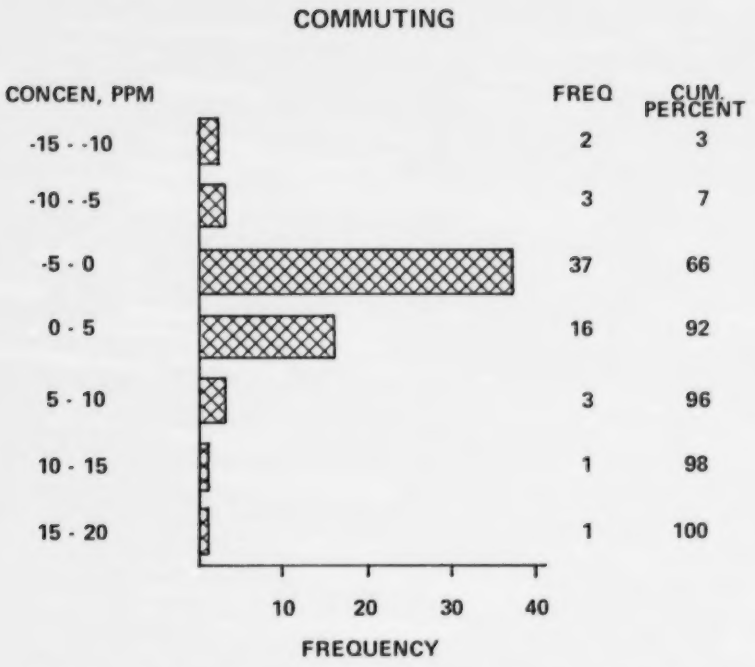


Figure 9. Frequency histograms of measurement differences (personal exposure minus fixed-site concentration) during 8-h exceedances in Phoenix.

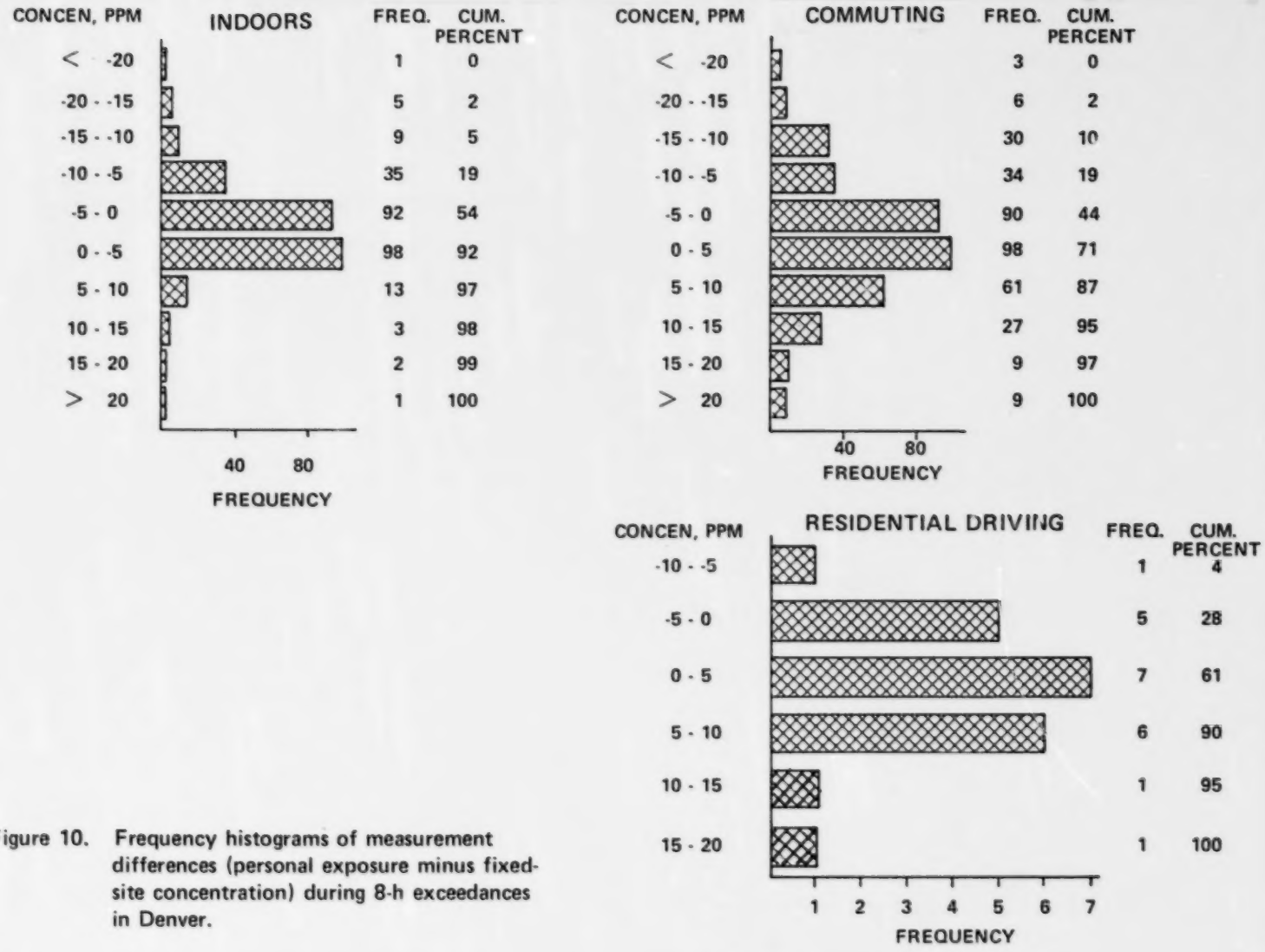


Figure 10. Frequency histograms of measurement differences (personal exposure minus fixed-site concentration) during 8-h exceedances in Denver.

$$\text{time-weighted average exposure} = \frac{\sum_{i=1}^{n} CO_i \cdot t_i}{\sum_{i=1}^{n} t_i} \quad (1)$$

where n = number of measurements recorded during an activity time period for the entire study

t_i = averaging time of exposure (min)

CO_i = average exposure for averaging time t_i

Table 4 shows the time-weighted average exposures in each of the five activities and the estimated maximum 8-h average exposure for a commuting office worker in each city. The 8-h average value is a time-weighted combination of the commuting (maximum of the morning and evening commute averages), office, store and restaurant average exposures. These values were computed by the following equation:

$$\text{maximum 8-h average} = 1/8\ (\text{maximum commuting exposure}) + 6/8\ (\text{office exposure}) + 1/16\ (\text{restaurant exposure} + \text{store exposure}) \quad (2)$$

This weighted combination assumes a 1-h commuting time, 6 hours in the office 1/2-h in a restaurant, and 1/2-h shopping time during the total time period of 8-h. Due to the high CO commuting levels, the commuting office worker in Los Angeles received the highest average exposure. This exposure (8.2 ppm) is slightly under the current 8-h standard. The time-weighted average indoor and commuting exposures in Los Angeles also are considerably higher than in the other three cities.

TABLE 4. AVERAGE EXPOSURE OF THE COMMUTING OFFICE WORKER IN EACH CITY

	Average exposure (ppm)					
City	Morning Commute	Office	Restaurant	Store	Evening Commute	Estimated for 8-h
Los Angeles	17.8	6.9	7.1	5.8	15.2	8.2
Denver	13.9	5.1	6.8	5.2	11.5	6.3
Stamford	6.8	3.0	5.1	2.4	6.0	3.6
Phoenix	10.9	1.9	3.4	1.6	6.9	3.1

The results of using the maximum of the daily time-weighted average exposures in each activity to estimate the maximum 8-h average exposure

are shown in Table 5. Under the worst case situation, the average 8-h maximum exposure is above the 8-h standard, for every city except Stamford, but this simulated result occurs only if the maximum exposure is received in each activity on the same day.

TABLE 5. MAXIMUM EXPOSURE OF THE COMMUTING OFFICE WORKER IN EACH CITY

	Maximum exposure (ppm)					
City	Morning Commute	Office	Restaurant	Store	Evening Commute	Estimated for 8-h
Los Angeles	24.6	13.8	13.0	20.3	18.9	15.5
Phoenix	27.6	10.4	10.3	5.6	12.2	12.2
Denver	20.8	9.1	14.3	15.5	21.5	11.4
Stamford	14.0	5.5	22.5	6.2	11.0	7.7

Tables 6 through 9 show the daily maximum 8-h ambient average at the urban fixed monitoring station in each city along with the daily time-weighted average exposures in the five activities. The daily maximum 8-h average commuting office worker exposures are also shown. In Stamford (Table 6), the daily maximum 8-h ambient average (station 1) varied from 2 to 13 ppm. These averages were generally higher than the maximum 8-h average commuting office worker exposures. In most cases, the average ambient levels were at least twice the level of th average commuting office worker exposures. The high restaurant exposures (>20 ppm) recorded in Stamford resulted from the high CO concentrations recorded at a diner monitoring location. Further descriptions of the restaurant monitoring sites used in Stamford are detailed further in Section 5.

The Los Angeles (Table 7) daily maximum 8-h ambient averages were roughly equivalent to the maximum commuting office worker exposures. This result can be partially explained by the generally high commuter and office exposures recorded in Los Angeles. The average commuter exposures ranged from 11 to 25 ppm, and the average office exposures varied from 3 to 14 ppm. Although commuter monitoring was conducted in Los Angeles for only 12 days, the 8-h commuting office worker average exposure exceeded the 8-h standard on 3 of these days and was within 1 ppm of the standard on 4 additional days.

In Phoenix (Table 8), the 8-h average commuting office worker exposures were generally the lowest of these recorded in this study. These exposures ranged from 2 to 5 ppm and were primarily a result of the low office exposures recorded in Phoenix.

The average commuter and indoor exposures recorded in Denver (Table 9) did not exceed the levels recorded in Los Angeles, but were substantially higher than levels recorded in Stamford and Phoenix. The majority of the morning and evening commuter exposures were above 10 ppm. However, only one 8-h average commuting office worker exposure exceeded the 8-h standard. With the exception of 5 monitoring days, the daily maximum 8-h ambient average was within 2 ppm of the 8-h commuting office exposure.

TABLE 6. DAILY LEVELS RECORDED IN STAMFORD: FIXED-SITE 8-H MAXIMUM CONCENTRATION AND WEIGHTED AVERAGE ACTIVITY AND COMMUTING OFFICE WORKER EXPOSURES[a]

Start day	Morning commute	Office	Restaurant	Store	Evening commute	8-h maximum exposure for commuting office worker	Fixed[b] site 8-h maximum
2/9	4.9	1.3	2.0	1.0	5.5	1.9	8.6
2/10	10.3	3.8	1.6	2.4	6.9	4.4	.
2/11	3.5	2.4	1.6	1.6	5.0	2.6	.
2/12	4.1	3.8	2.1	2.0	5.9	3.9	8.1
2/13	6.3	5.5	3.4	4.8	8.3	5.7	2.6
2/17	12.3	5.3	2.8	5.8	10.0	6.1	10.6
2/18	13.9	5.3	8.3	6.2	11.0	6.6	11.2
2/19	10.7	3.5	22.5	4.9	9.7	5.7	2.4
2/20	4.4	3.4	3.8	2.3	9.5	4.1	.
2/23	5.3	1.8	2.6	2.4	6.2	2.4	.
2/24	9.4	4.1	6.2	4.9	8.3	5.0	7.2
2/25	7.6	2.9	1.8	0.9	4.4	3.3	10.9
2/26	4.7	2.1	14.7	1.5	4.2	3.2	7.1
2/27	4.3	2.5	21.9	1.2	4.1	3.8	8.4
3/2	13.7	3.9	20.8	3.9	6.2	6.2	13.1
3/3	8.9	4.9	3.7	2.5	3.6	5.2	9.3
3/4	6.7	2.1	2.8	.	7.9	.	9.0
3/5	7.5	4.6	1.2	3.2	9.7	4.9	5.4
3/6	2.4	2.8	2.8	1.1	4.8	2.9	9.9
3/9	7.7	3.1	1.4	1.9	4.8	3.5	12.4
3/10	6.4	2.7	2.1	1.1	6.0	3.0	11.8
3/11	6.3	1.6	2.8	1.7	7.5	2.4	13.6
3/12	4.7	2.0	9.4	1.8	6.1	2.9	11.4
3/13	7.8	1.8	1.0	1.4	4.7	2.5	.
3/16	14.0	.	.	.	3.0	.	.
3/17	5.4	2.7	0.8	0.9	3.7	2.8	.
3/18	5.0	2.6	2.5	1.3	6.9	3.0	11.6
3/19	11.2	4.2	3.2	2.1	5.9	4.9	12.8
3/20	6.9	2.6	4.2	1.8	6.3	3.2	13.4
3/23	9.6	2.0	9.9	3.3	5.7	3.5	5.5
3/24	6.0	2.3	.	1.5	6.2	.	8.5
3/25	4.6	1.3	0.2	1.0	4.8	1.7	6.2
3/26	6.0	2.7	3.1	2.9	4.7	3.1	7.7
3/27	6.8	3.2	8.2	2.1	4.5	3.9	11.3
3/30	5.3	2.2	2.5	0.7	6.0	2.6	5.7
3/31	3.3	1.9	1.3	1.8	3.8	2.1	7.8
4/1	4.2	1.5	2.1	0.1	3.7	1.8	1.7
4/2	3.3	1.7	0.5	1.0	3.6	1.8	7.4
4/3	6.8	2.3	1.3	4.2	4.6	2.9	8.7

[a]Missing data denoted by period
[b]Station 1

TABLE 7. DAILY LEVELS RECORDED IN LOS ANGELES: FIXED-SITE 8-H MAXIMUM CONCENTRATION AND WEIGHTED AVERAGE ACTIVITY AND COMMUTING OFFICE WORKER EXPOSURES[a]

Start day	Morning commute	Office	Restaurant	Store	Evening Commute	8-h maximum exposure for commuting office worker	Fixed site 8-h maximum
1/12	16.9	6.6	5.5	5.5	16.5	7.7	10.1
1/13	.	6.6	8.5	5.3	.	.	8.3
1/14	.	7.9	9.0	5.3	.	.	10.9
1/15	.	9.6	10.5	7.0	.	.	11.6
1/16	15.8	7.3	9.0	6.7	15.3	8.5	8.7
1/19	.	7.2	13.0	7.2	.	.	9.0
1/20	.	5.2	8.5	4.7	.	.	7.5
1/21	19.6	10.6	10.0	10.7	18.9	11.7	18.6
1/22	.	9.6	8.5	10.3	.	.	13.9
1/23	.	2.9	4.5	2.7	.	.	5.6
1/26	.	11.7	8.5	5.8	.	.	8.7
1/27	.	3.0	4.0	3.7	.	.	9.0
1/28	21.2	3.9	4.5	2.5	10.3	6.0	5.7
1/29	.	2.3	2.0	2.0	.	.	6.3
1/30	.	4.8	6.0	2.7	.	.	9.0
2/02	.	8.1	9.5	7.0	.	.	11.0
2/03	22.7	13.2	9.0	9.0	16.5	13.9	8.8
2/04	.	7.9	8.0	5.2	.	.	10.9
2/05	.	13.4	10.0	7.5	.	.	11.5
2/06	24.6	6.3	10.0	6.2	17.5	8.8	9.6
2/09	16.1	5.0	3.5	3.8	16.9	6.3	6.3
2/10	.	5.8	7.5	5.0	.	.	7.8
2/11	.	5.1	6.0	4.2	.	.	7.4
2/12	.	7.4	11.0	6.2	.	.	8.6
2/13	19.2	9.0	5.0	8.2	18.4	10.0	9.9
2/17	.	5.1	3.0	5.8	.	.	8.4
2/18	.	5.3	7.5	5.8	.	.	12.3
2/19	16.4	6.3	4.5	4.8	12.8	7.4	15.1
2/20	.	3.1	5.0	2.3	.	.	12.0
2/23	.	6.4	4.5	4.8	.	.	11.0
2/24	.	6.6	8.0	5.0	.	.	5.5
2/25	.	3.3	5.0	3.2	.	.	3.8
2/26	14.0	4.2	5.5	4.2	11.6	5.5	4.9
2/27	.	4.2	9.0	20.3	.	.	7.6
3/02	.	4.8	5.5	3.8	.	.	6.5
3/03	10.8	8.4	9.0	5.8	13.2	8.9	8.1
3/05	.	13.8	3.0	3.8	.	.	5.0
3/09	17.9	7.0	8.0	5.8	12.1	8.4	8.1
3/10	.	9.0	7.5	5.7	.	.	8.9

[a]Missing data denoted by period

TABLE 8. DAILY LEVELS RECORDED IN PHOENIX: FIXED-SITE 8-H MAXIMUM CONCENTRATION AND WEIGHTED AVERAGE ACTIVITY AND COMMUTING OFFICE WORKER EXPOSURES[a]

Start Day	Morning commute	Office	Restaurant	Store	Evening commute	8-h maximum exposure for commuting office worker	Fixed site 8-h maximum
1/27	14.2	1.5	.	0.2	8.1	.	6.6
1/28	9.9	0.9	.	0.5	8.7	.	3.5
1/30	11.3	2.2	.	0.0	4.1	.	3.4
1/31	6.5	.	.	0.0	2.4	.	3.5
2/01	4.4	.	.	0.7	3.1	.	5.9
2/02	27.6	10.4	.	2.9	9.2	.	9.2
2/04	17.7	2.6	.	2.9	8.3	.	7.8
2/05	19.8	3.1	.	1.1	7.7	.	10.4
2/06	16.2	3.0	.	2.8	12.2	.	9.1
2/10	12.3	4.4	.	2.5	9.7	.	5.2
2/11	12.9	1.5	3.8	2.4	7.1	3.1	6.3
2/13	14.9	3.0	10.3	5.6	9.5	5.1	10.4
2/14	7.7	.	.	2.0	6.1	.	11.5
2/15	.	.	.	1.3	4.9	.	4.5
2/17	13.8	0.8	2.9	1.7	7.8	2.6	7.6
2/18	13.2	1.6	4.2	3.0	7.2	3.3	7.1
2/19	11.4	0.9	5.1	1.8	11.6	2.5	10.3
2/20	15.7	0.7	4.4	2.1	.	2.9	3.2
2/24	9.6	1.5	2.7	1.7	9.4	2.6	7.6
2/25	8.3	1.1	2.2	1.2	4.2	2.1	2.0
2/27	13.5	3.7	5.8	4.0	9.0	5.0	5.8
2/28	8.7	.	.	1.7	3.5	.	5.0
3/01	.	.	.	0.4	5.5	.	1.1
3/02	8.6	0.5	0.0	1.0	5.9	1.5	1.0
3/04	7.7	0.7	3.8	1.8	6.8	1.9	1.1
3/05	5.7	0.8	0.9	0.8	5.5	1.4	1.4
3/06	6.4	0.3	0.7	1.3	6.0	1.1	4.4
3/10	10.6	0.4	3.3	0.9	5.1	1.9	4.8
3/11	9.0	0.1	3.8	2.0	7.2	1.6	5.1
3/13	5.1	0.8	2.1	0.4	6.2	1.5	1.6
3/14	.	.	2.9	0.4	4.6	.	3.3
3/15	.	.	1.8	0.1	2.5	.	4.2
3/16	5.6	1.7	2.1	2.6	5.2	2.3	4.4
3/17	9.2	1.3	0.8	1.7	5.2	2.3	2.6
3/18	.	.	.	.	5.6	.	5.4
3/19	8.7	1.3	1.0	2.3	9.5	2.4	6.6
3/20	7.4	1.3	1.0	1.6	4.9	2.1	.

[a]Missing data denoted by period

TABLE 9. DAILY LEVELS RECORDED IN DENVER: FIXED-SITE 8-H MAXIMUM CONCENTRATION AND WEIGHTED AVERAGE ACTIVITY AND COMMUTING OFFICE WORKER EXPOSURES[a]

Start day	Morning commute	Office	Restaurant	Store	Evening commute	8-h maximum exposure for commuting office worker	Fixed site 8-h maximum
1/27	19.0	7.0	2.4	5.9	17.8	8.2	6.4
1/28	19.5	9.1	7.5	7.9	15.7	10.3	9.8
1/29	13.2	3.7	3.5	4.9	11.2	4.9	6.8
1/30	10.2	5.3	0.2	5.5	16.1	6.3	7.5
2/02	16.5	4.6	9.5	3.8	10.5	6.4	6.0
2/03	19.0	6.4	10.9	9.2	13.2	8.4	8.8
2/04	15.9	3.2	3.5	5.9	14.2	5.0	7.4
2/05	17.7	4.5	5.7	3.4	11.8	6.2	6.2
2/06	18.5	.	10.6	.	11.4	.	8.3
2/09	13.1	4.7	7.6	6.7	12.3	6.1	6.5
2/10	10.3	0.9	1.9	.	8.7	.	4.9
2/11	14.5	7.4	7.6	4.5	14.6	8.2	9.7
2/13	9.3	4.9	10.5	7.4	13.6	6.5	8.2
2/14	5.1	.	14.3	15.5	21.5	.	15.0
2/15	.	.	.	2.0	10.4	.	3.6
2/17	16.6	5.8	12.6	3.5	4.9	7.4	5.9
2/18	12.3	6.9	10.4	7.6	14.0	8.0	4.7
2/19	10.5	3.7	9.7	4.0	15.9	5.6	7.2
2/20	13.1	5.4	6.1	3.1	7.4	6.2	6.8
2/23	20.8	.	5.9	.	.	.	5.0
2/24	19.1	7.5	7.0	6.8	11.0	8.9	11.6
2/25	12.9	3.7	3.6	3.5	13.2	4.9	6.3
2/26	15.2	6.1	4.3	7.1	10.4	7.2	9.1
2/27	8.8	2.6	3.4	4.9	10.4	3.8	4.0
3/02	12.9	5.5	4.6	3.9	11.5	6.2	5.4
3/03	14.2	6.5	5.7	6.1	11.9	7.4	.
3/06	17.6	3.4	8.9	4.9	10.9	5.6	6.8
3/07	2.2	.	2.5	3.1	10.0	.	2.1
3/08	.	.	.	6.4	10.3	.	2.5
3/09	14.2	5.7	5.9	5.5	10.0	6.7	4.3
3/10	12.1	3.4	7.4	2.5	8.1	4.7	5.2
3/11	13.8	4.9	9.8	2.6	9.9	6.2	3.6
3/12	15.4	3.6	7.0	1.4	11.0	5.1	5.5
3/13	11.5	.	4.4	.	10.1	.	4.2
3/16	10.4	4.5	5.1	5.7	10.6	5.4	4.8
3/17	9.1	.	.	.	6.1	.	3.6
3/18	10.6	7.3	9.0	3.7	10.5	7.6	4.5
3/19	10.7	2.9	8.6	1.9	10.5	4.2	4.4
3/20	12.1	3.0	6.1	5.4	11.8	4.5	5.8

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SECTION 5

SAMPLING DESIGN AND STATISTICAL ANALYSES BY CITY

STAMFORD

Sampling Design

Personal exposures were measured in the three microenvironments described in Section 2. Ambient data were collected at two fixed sites. Monitoring procedures are detailed in a report by Rumba (1981). The Stamford meteorological station provided meteorological data, including wind speed (mi/h), air temperature (/F), and solar radiation (langleys/min).

Personal Exposure Monitoring

Indoor--

Trained personnel carried General Electric personal portable CO monitors into various stores, offices, and public buildings in the area immediately surrounding the two fixed monitoring stations. At each location, integrated CO levels were recorded for 10 to 30 min. Then the technician went on to the next location. Figure 11 shows the locations of the 20 indoor exposure sites; Table 10 provides a description of each. Eleven locations were in the area directly surrounding the two fixed monitoring stations. Eight locations were 0.5 to 1 mi from these stations.

Errand traffic exposure in the central business district (listed as location 12) was also included in this phase of the monitoring. Errand traffic exposure was estimated each day by driving a fixed grid pattern for 30 min in the central business district. Integrated CO levels were recorded every 10 min.

Monitoring at all 20 locations was randomized each day. The 11 locations immediately surrounding the fixed sites were designated as group 1; the 8 locations 0.5 to 1 mi away were designated as group 2. Each day one group was sampled in the morning and the other was sampled in the afternoon. The morning and afternoon schedules were randomly interchanged over the entire monitoring period. Also, the sequence of sampling locations within each group was randomized. The errand traffic exposure fixed grid pattern was driven during the interchange period.

Commuting--

This monitoring was conducted between 7 and 9 a.m. and again at 4 to 6 p.m. each day. Two trained technicians drove two predetermined major commuting

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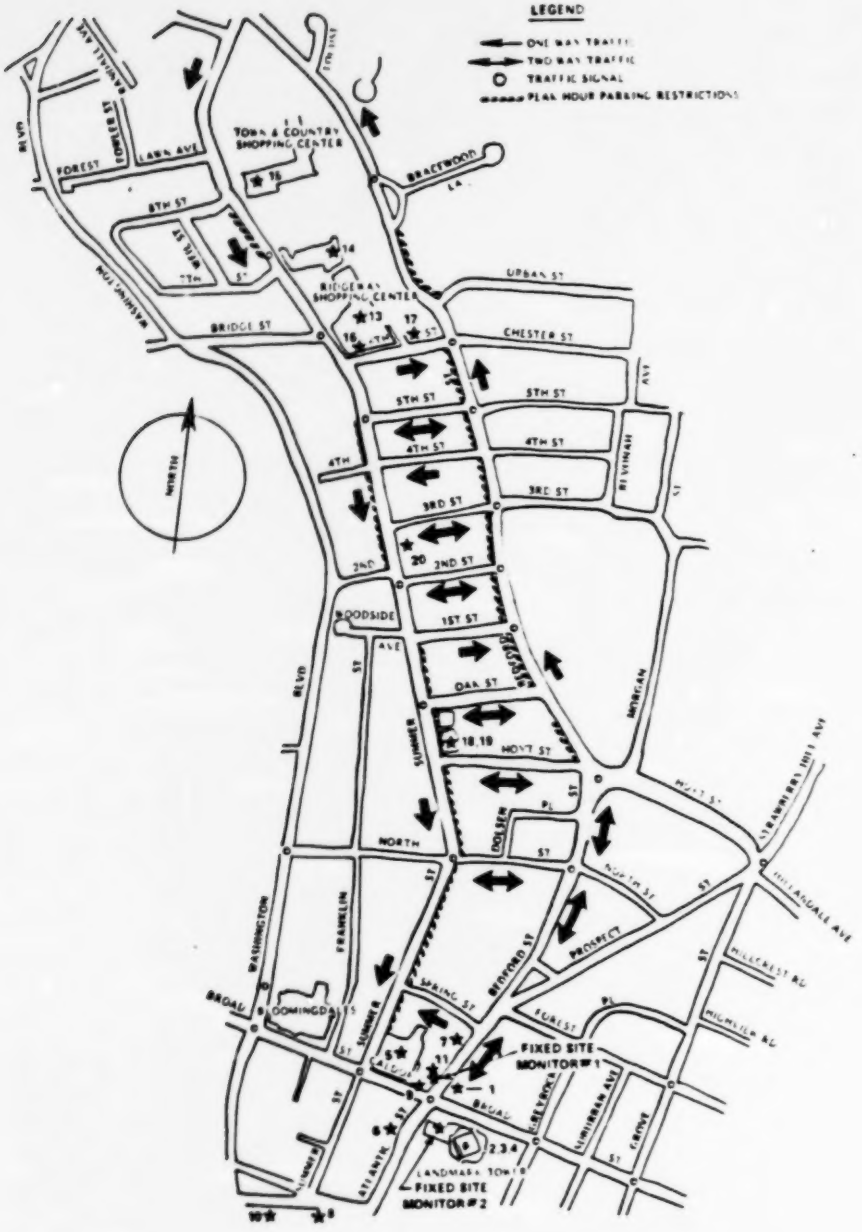

Figure 11. Indoor exposure and fixed-site monitoring locations in Stamford.

TABLE 10. INDOOR EXPOSURE MONITORING LOCATIONS IN STAMFORD

Location number	Description	Location category
1	McDonald's Restaurant	Restaurant
2	Landmark Tower - 20th floor	Office bldg. - garage beneath
3	Landmark Tower - 8th floor	Office bldg. - garage beneath
4	Landmark Tower - Garage	Underground garage
5	Caldor Department Store	Store
6	Brock Press Office Supplies	Store
7	Foot Form Shoe Store	Store
8	Town Hall	Public bldg.
9	Library	Public bldg.
10	Century Office Bldg.	Office bldg. - no parking beneath
11	Monitor at inlet to fixed-site probe (station 1)	Street corner
12	Drive fixed grid in central business district	Errand exposure
13	Gran Central Market	Store
14	40 Boutiques	Store
15	Grand Union Super Market	Store
16	Ridgeway Office Bldg.	Office bldg. - no parking beneath
17	Ridgeway Post Office	Public bldg.
18	1111 Summer St. - lobby	Office bldg. - garage beneath
19	1111 Summer St. - 6th floor	Office bldg. - garage beneath
20	Century Diner	Restaurant

routes to and from the Stamford central business district (Figure 12). Each route constituted approximately 30 min of driving time. During each driving segment the driver recorded the time, location, traffic density (light, moderate, or heavy), and integrated CO reading. The sequence of routes was randomized each day during the monitoring period.

Residential Driving--

This monitoring was conducted inside a car traveling on streets of low traffic density in residential areas surrounding the central business district. Trained personnel drove four predetermined 15-mi routes that were no closer than 1 mi to the fixed stations (Figure 13). The time, location, and integrated CO value were recorded every 10 min.

Fixed-Site monitoring

The two fixed-site locations are shown in Figure 11. Monitoring station 1 was maintained by the State of Connecticut. The probe was located approximately 25 ft from the corner of the intersection of Bedford and Broad Streets and about 8 ft above ground level. During this study, the building directly behind the library on Bedford Street was undergoing heavy construction. Heavy equipment was frequently used in close proximity to the probe. In addition, during this study this intersection was congested with heavy traffic for most of the day, and vehicle exhaust was emitted only a few feet from the probe inlet.

Station 2 was set up diagonally across the intersection from station 1. The probe was located on the south side of the building facing Broad Street, approximately 75 ft from the center of the intersection and 18 ft above ground level. The probe extended about 2 ft from the wall of the building, and was partially obstructed to the east by the protruding wall of the connecting building.

Statistical Analyses

Comparison of Indoor and Fixed-Site CO Concentrations--

An independent t-statistic was used to test the hypothesis that the arithmetic mean for each indoor location was equivalent to the arithmetic mean for fixed site 1 and for fixed site 2. The t-test used was based on the assumption that the variances of the two groups in each test were unequal. This assumption was made after the variances were determined to be unequal (at a 5% probability level) for all comparisons.

The significance levels of each t-test suggested that the indoor exposure were not statistically different from the fixed site 1 concentrations for three locations: Landmark Tower - 20th floor; the Library; and, as a quality assurance comparison check, the inlet of fixed site 1. The indoor exposures were not statistically different from the fixed site 2 concentrations for 12 of the 20 locations sampled: Caldor Department Store, Brock Press Office Supplies, Foot Form Shoe Store, Town Hall, Century Office Building, Gran Central Market, 40 Boutiques, Grand Union Super Market, Ridgeway Office Building, Ridgeway Post Office, 1111 Summer St.-6th floor and lobby. Thus, fixed site 2 appears to be more representative of indoor com-

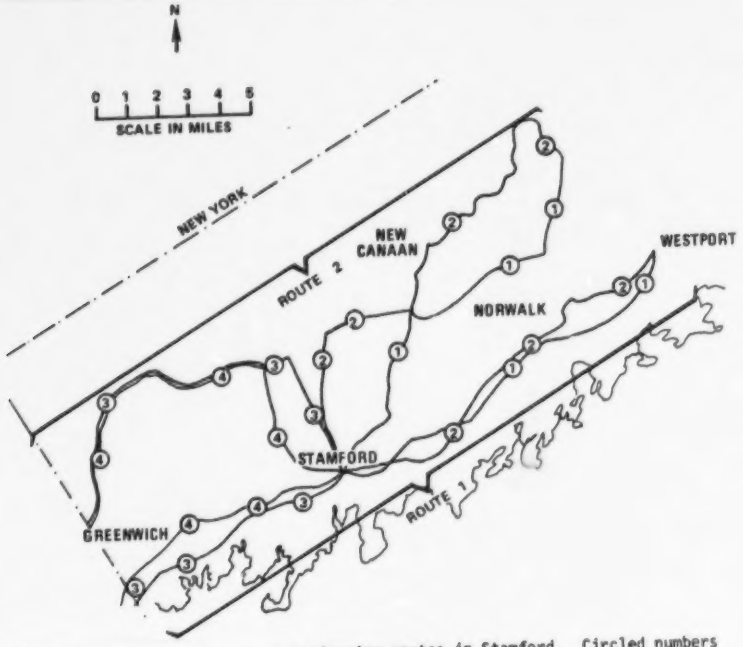

Figure 12. Commuting exposure monitoring routes in Stamford. Circled numbers indicate the four legs of each of the two routes.

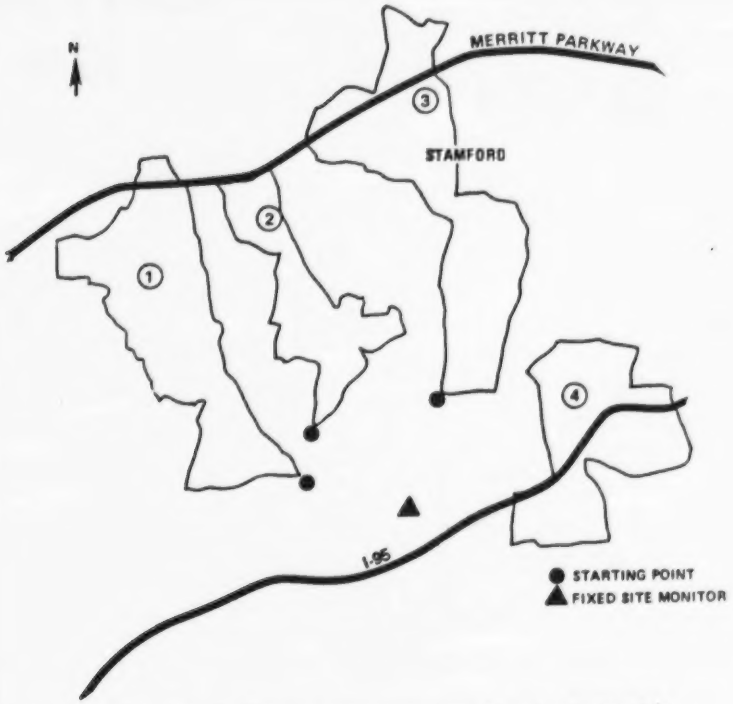

Figure 13. Residential driving exposure monitoring routes in Stamford.

mercial locations in Stamford. This result is probably due to the close proximity of site 1 to automobile exhaust fumes and to construction activity.

The indoor exposures at the Landmark Tower garage and the Century Diner were significantly higher than the concentrations recorded at fixed site 1. This important result provides evidence that CO levels at specific locations can exceed measurements recorded at a fixed site located near a heavily congested intersection.

Figure 14 is a scatter plot of the concentrations at fixed site 1 vs. personal exposures recorded at the inlet to the fixed monitor superimposed by the fitted least-squares linear regression line. Surprisingly, the correlation coefficient between these two groups of measurements is moderately low (0.72). Given the close proximity of the measurement locations, one would expect to see a stronger relationship between these two groups of CO concentrations.

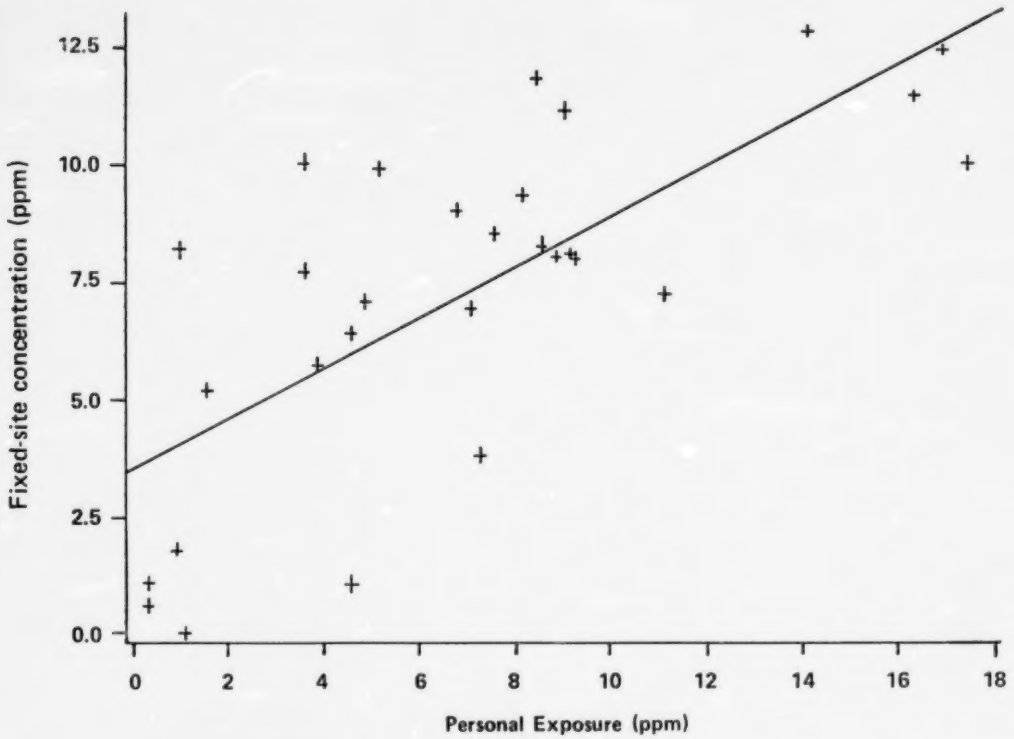

Figure 14. Scatter plot of concentrations at fixed site 1 vs. personal exposures recorded near this site in Stamford.

Effects of Time of Day and Location on Indoor Exposures

An analysis of variance was used to examine the influence of time (hour of day), meteorological conditions, and location on indoor exposures. A multicollinearity test (Farrar and Glauber, 1967) was used to determine if the meteorological variables were linearly related with time of day. As expected, air temperature and solar radiation were highly related with time of day. Wind speed was also related to time of day, but not to the degree that air temperature and solar radiation were. In order to reduce the instability in the analysis of variance caused by these linear relationships among the independent variables, the meteorological variables were not included in the initial analysis. Also, a logarithmic transformation was performed on the CO data to help stabilize the error variance across increasing concentration levels and improve the normality assumption of the analysis of variance. The model used was

$$\log (CO)_{ijk} = \mu + L_i + TP_j + (L*TP)_{ij} + \epsilon_{ijk} \qquad (3)$$

where CO_{ijk} denotes the k^{th} observation in the i^{th} location during the j^{th} time period, μ is a general mean, and ϵ_{ijk} is the random error of the $(ijk)^{th}$ observation. Three time periods were used in the analysis: morning (6-10 a.m.), midday (11 a.m.-1 p.m.), and afternoon (2-4 p.m.).

The results indicated that exposures differed significantly (at a 5% probability level) among the 20 locations and among locations across time categories. To identify groups of the 20 locations for which exposures were similar, Duncan's Multiple Range Test (Duncan, 1975) was used to compare the location geometric means obtained by Equation 3. Unfortunately, the groups of statistically different means (5% probability level) overlapped, and it was difficult to precisely identify non-overlapping groups of locations. To overcome this problem, a cluster analysis (Johnson, 1967) was used to identify groups of statistically similar location arithmetic means. The standard error of each location mean was less than 20% of the mean value. The resulting groupings of locations are indicated by the dotted lines in Table 11. Interestingly, the 20th floor of the Landmark Tower had higher exposures than the 8th floor. Also, the lobby and 6th floor of 1111 Summer St. (office building with garage beneath) had significantly lower exposures than the 8th and 20th floors of the Landmark Tower (also an office building with underground garage).

If we are only interested in the arithmetic average exposures, it might be acceptable to lump these indoor locations into several microenvironment types because they have similar average levels. However, two or more indoor locations might accidentally have the same average exposures, but the distribution of exposures at these locations may be completely different. Thus, locations shall not be grouped into microenvironment types solely on the basis of arithmetic mean exposures. Continuing efforts are planned to examine the use of mean exposure values and distributional properties to combine microenvironment locations into microenvironment types.

TABLE 11. SUMMARY STATISTICS: INDOOR EXPOSURES IN STAMFORD

Group	Description	Location number	Location category	Sample size	Arithmetic mean(ppm)	Standard error of mean
1	1111 Summer St.-lobby	18	Office bldg.-garage beneath	36	1.50	0.28
	Century Office Bldg.	10	Office bldg.-no parking beneath	36	1.57	0.27
	40 Boutiques	14	Store	35	1.64	0.28
	Grand Union Super Market	15	Store	34	1.68	0.29
	1111 Summer St.-6th floor	19	Office bldg.-garage beneath	37	1.69	0.26
2	Ridgeway Office Bldg.	16	Office bldg.-no parking beneath	35	1.80	0.26
	Ridgeway Post Office	17	Public bldg.	36	1.86	0.23
	Town Hall	8	Public bldg.	35	1.93	0.22
3	Caldor Dept. Store	5	Store	38	2.18	0.25
	Foot Form Shoe Store	7	Store	36	2.36	0.34
4	Gran Central Market	13	Store	34	2.62	0.37
	Brock Press Office Supplies	6	Store	36	2.72	0.35
5	McDonald's Restaurant	1	Restaurant	121	3.49	0.29
6	Landmark Tower-8th floor	3	Office bldg.-garage beneath	38	3.96	0.42
	Drive fixed grid in central business district	12	Errand exposure	85	4.11	0.30
7	Library	9	Public bldg.	39	5.20	0.54
	Landmark Tower 20th floor	2	Office bldg.-garage beneath	38	5.47	0.41
8	Monitor at Inlet to Fixed Site Probe	11	Street corner	34	7.38	0.82
9	Landmark Tower Garage	4	Underground garage	38	12.09	1.11
10	Century Diner	20	Restaurant	130	16.00	1.11

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LOS ANGELES

Sampling Design

In addition to the three microenvironment types summarized in Section 2, outdoor exposures were also recorded. Ambient CO levels were monitored at 10 fixed sites in the Los Angeles County area. Locations of the fixed monitoring stations, commute routes, and residential monitoring areas are shown on the map in Figure 15. The monitoring procedures are summarized below. The procedures are detailed further in a report by Ziskind (1981). No meteorological data were provided by the contractor.

Personal Exposure Monitoring

Subject - Directed Monitoring--

Six participants were selected and trained in the operation and reading of the General Electric personal CO monitors. The participants were instructed to take CO data at 1-h maximum intervals while engaged in a variety of activities throughout the Los Angeles County area. These activities included commuting, working, activities at home, cooking, leisure, and errands. While engaged in these activities, the participants recorded the presence or absence of smokers and the ventilation conditions. Although CO readings were requested at a maximum of 1-h intervals, some measurements were recorded at intervals of greater than 1 h.

Commuting--

Monitoring was conducted during the morning and afternoon rush hours on 12 selected days. A trained technician drove four common commuter routes through the Los Angeles area. Starting times were approximately 7 a.m. and 4 p.m. The starting route was alternated between the first and third routes, with the entire four routes driven each morning and afternoon. For each route, the technician recorded elapsed time, integrated CO concentration (ppm), subjective determination of traffic density (light, medium, or heavy), and comfort-ventilation state (air conditioning, heat, windows/vents open, windows/vents closed).

Indoor--

Indoor pedestrian monitoring took place each day. The measurement procedure was subdivided into three intervals. From 10:10 a.m. until 12:05 p.m., CO readings were taken in eight businesses in a retail and commercial area of West Los Angeles. Each reading was taken over a 10-min interval. No data were taken during the walk from one location to the next. The second interval consisted of a 30-min errand drive exposure. The third measurement interval was conducted in the afternoon of each day and consisted of 10 readings obtained by the same procedure used in the morning. The monitoring locations were grouped according to the following categories: grocery store, public building, office building with and without underground garage, and errand traffic exposure.

Residential Driving--

Four residential areas representative of the residential exposures to CO of a significant number of people in the Los Angeles area were selected. The

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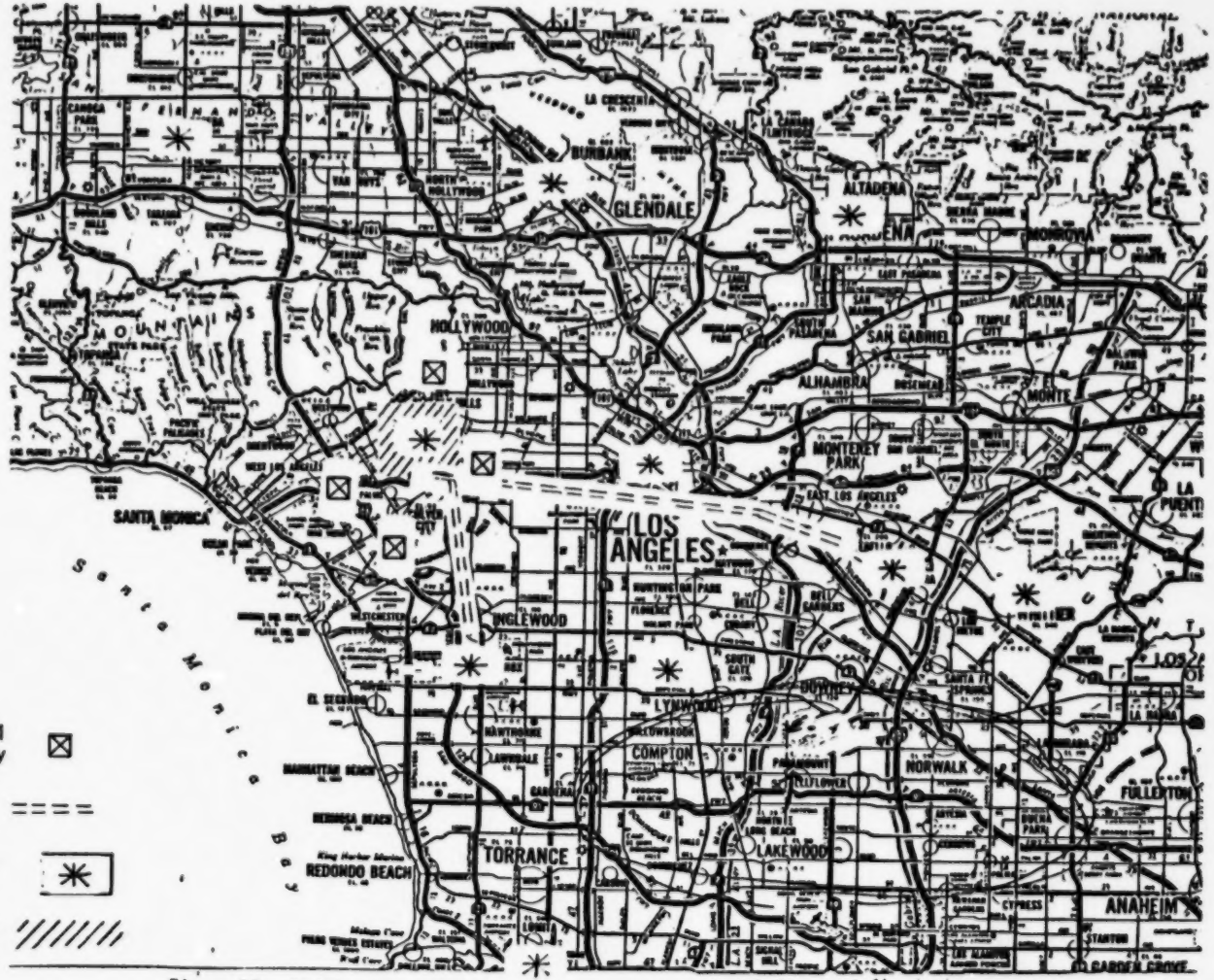

Figure 15. Indoor pedestrian, commuting, residential driving, and fixed-site monitoring locations in Los Angeles.

technician drove at 30 mi/h for 30 min in each area taking three CO readings at 10-min intervals. Driving started at 9 a.m. and concluded at 2 p.m., with a 30-min lunch break. The driver also recorded elapsed mileage, heating, air conditioning, and window/ ventilation conditions.

Fixed-Site Monitoring

Ambient CO levels (hourly averages) were obtained from 10 air quality monitoring stations in Los Angeles County.

Comparison to Los Angeles Pilot Study

In the Los Angeles Pilot Study (Ziskind, 1981), nine subjects selected from the general population were employed in a 3-mo monitoring project. The subjects carried personal CO monitors and recorded exposures during distinct activities such as commuting or working. This direct approach of permitting human subjects from the general population to sample microenvironments according to their own activity patterns differs from the subject-directed monitoring of the winter study, where certain microenvironments were selected from a frame of possible microenvironments. However, it is still possible possible to compare weekday activity arithmetic mean exposures between the two studies (Table 12).

TABLE 12. LOS ANGELES PILOT STUDY AND WINTER STUDY: ARITHMETIC MEANS BY ACTIVITY

	Arithmetic mean (ppm)	
Activity	Pilot Study	Winter Study
At home	4.6	3.2
At work	4.3	3.5
Commuting	10.0	9.1
Errand driving	9.2	9.2
Leisure/recreation	6.5	3.9

The only major difference between the two studies occurs in the leisure activity exposures. If one assumes that the weekday percent activity times found in the pilot study also apply to the winter study, these percents can be applied to the activity arithmetic means to determine an average weekday exposure for each study: 5.3 ppm for the pilot study and 4.4 ppm for the winter study. The primary reason for this difference is the lower work exposures found in the winter study, which were assumed to represent 52% of the average weekday exposure based on activity patterns in the pilot study. The weekday commuting and errand driving arithmetic means were determined from all the weekday exposures recorded during the study in these categories Thus, these averages differ from the average commute level shown in Table 3 (16.4 ppm) which was calculated solely from exposures that could be matched to fixed site concentrations by time.

Statistical Analyses

Subject-directed Exposures--

An analysis of variance was performed on the logarithmically transformed subject-directed data to determine the effect of various activities on these exposures. (The effects of smoking and ventilation conditions are described by Ziskind [1981]). The model used was

$$\log (CO)_{ijk} = \mu + A_i + (IO)_j + \varepsilon_{ijk} \qquad (4)$$

where CO_{ijk} denotes the k^{th} observation in the i^{th} activity category during the j^{th} indoor/outdoor activity status, μ is a general mean and ε_{ijk} is the random error of the $(ijk)^{th}$ observation. The results provided strong evidence that exposures differed significantly (5% probability level) among activities and between indoors and outdoors.

To identify groups of activities among which exposures were significantly different, the geometric means obtained by Equation 4 were evaluated by Duncan's Multiple Range Test. The results are shown in Table 13.

TABLE 13. LOS ANGELES INDOOR/OUTDOOR EXPOSURE GEOMETRIC MEANS BY ACTIVITY

Grouping*	Activity	n	Geometric mean (ppm)
A	Commuting	251	7.7
B	Errand driving	104	5.5
C	At home/cooking	54	2.9
C	Leisure/recreation	93	2.7
C	At work	751	2.3
C	At home	557	2.3

*Means within a grouping are not significantly different.

That the commuting and errand exposure geometric means were significantly higher than the others is probably because of the greater exposure to automobile exhaust fumes when driving.

The outdoor exposures were significantly higher than the indoor exposures. The indoor geometric mean was 2.3 ppm (n = 1437) while the outdoor mean was 6.5 ppm (n = 399). Commuting and errand driving exposures were included in the outdoor activity classification.

Effect of Time of Day on Commuting Exposures--

An analysis of covariance was used to determine if time of day had a statistically significant effect on commuting exposures. The model used was

$$\log (CO)_{ijklm} = \mu + M + T_i + (CVS)_j + R_k + (TP)_\ell + (T * CVS)_{ij} + \varepsilon_{ijklm} \qquad (5)$$

where CO_{ijklm} denotes the m^{th} observation during the i^{th} traffic density, j^{th} comfort state, k^{th} route, and ℓ^{th} time period. M denotes the elapsed mileage of each observation, μ is the general mean and ε_{ijklm} is the random error of the $(ijklm)^{th}$ observation. Two time periods were used in the analysis: morning (6-10 a.m.) and afternoon (2-4 p.m.). Morning commuting exposures were significantly higher (5% probability level) than afternoon exposures. The morning geometric mean was 16.9 ppm (n=48); the evening mean was 13.7 ppm (n=48).

Effect of Location on Indoor Pedestrian Exposures--

An analysis of variance was used to determine if there were significant differences in indoor pedestrian exposures among location categories. The model used was

$$\log(CO)_{ij} = \mu + (LC)_i + \varepsilon_{ij} \qquad (6)$$

where CO_{ij} denotes the j^{th} observation in the i^{th} location category, μ in the general mean and ε_{ij} is the random error of the $(ij)^{th}$ observation. The analysis indicated that exposures did differ significantly among location categories (Table 14).

TABLE 14. LOS ANGELES INDOOR PEDESTRIAN EXPOSURE GEOMETRIC MEANS BY LOCATION CATEGORY

Grouping*		Location category	n	Geometric mean (ppm)
	A	Errand traffic exposure	39	9.0
	B	Grocery store	77	6.1
C	B	Office bldg garage beneath	156	5.3
C	B	Public bldg.	78	5.1
C	B	Office bldg.-no garage beneath	156	5.0
C		Store	234	4.6

PHOENIX

Sampling Design

Trained technicians measured personal exposures while engaging in different activities in the three microenvironment types summarized in Section 2. These CO averages were recorded for time intervals ranging from 10 to 40 min in most cases. Also, ambient concentrations were recorded at both an urban and an urban-residential fixed site. Locations of the fixed sites, commute routes, and residential monitoring areas are shown on the map in Figure 16. The monitoring procedures are summarized below. The procedures are detailed in a report by Acciani (1981). No meteorological data were provided by the contractor.

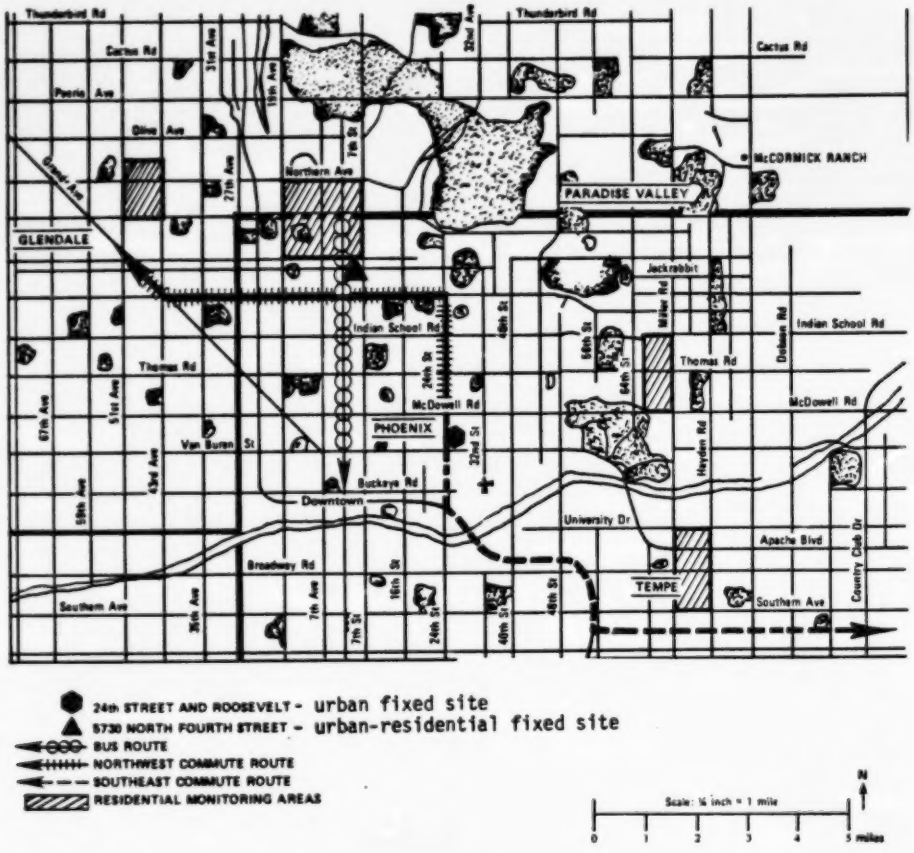

Figure 16. Commuting, residential driving, and fixed- monitoring locations in Phoenix.

Personal Exposure Monitoring

Indoor--

Two trained technicians wore portable CO monitors while engaging in various indoor working, eating, and shopping activities in Phoenix. The technicians recorded the date, location, time, and CO average exposure for each activity. The resulting data were categorized by location: restaurant, store, office, or public building. Monitoring was also conducted inside the urban fixed station.

Commuting--

The monitoring team recorded CO levels and traffic densities (light, average, or heavy) while driving along several major commuting routes in the Phoenix area. The drivers maintained legal speed limits (25 to 35 mi/h on city streets, and 55 mi/h on freeways). The exposure monitor rested on the console or on the area over the drive shaft between the two front passenger

seats. The cars were late-model Ford Mustangs and were continuously checked for possible CO contamination. The two technicians also recorded CO levels and traffic densities while riding city buses and while walking along downtown streets. The commuting exposure data were categorized as follows: bus, automobile, downtown driving, or downtown walking.

Residential Driving--

The monitoring team drove through several residential areas of Phoenix. The monitoring details were identical to those for commuting exposures.

Fixed-Site Monitoring

The urban monitoring station was located at the corner of 24th and Roosevelt Streets. This intersection had a high traffic density. The sampling port was located approximately 10 ft above the ground and 8 ft off Roosevelt Street. A Bendix nondispersive infrared monitor recorded hourly CO concentrations continuously from January 28 to March 20.

The urban-residential station was located at 5730 N. Fourth Street. Here a General Electric portable personal CO monitor was employed in the field. The instrument recorded average concentrations for at least 1 h from about 2 p.m. to 12 a.m. every day the monitoring team resided in Phoenix. The data obtained from this site are representative of a residential environment and provide an estimate of the level of CO exposure for individuals who reside away from motor vehicle traffic.

Statistical Analyses

Summary Statistics--

Summary statistics for the personal exposures are shown in Table 15. The mean level of the automobile commuting exposures was considerably higher than the mean levels of the other subgroups. In general, the commuting exposures were approximately 3 times higher than the indoor exposures based on the respective arithmetic mean values.

Effects of Time of Day and Location on Indoor Exposures--

An analysis of variance was performed on the logarithmically transformed indoor exposure data to determine if these concentrations differed significantly among morning (6-10 a.m.), afternoon (2-4 p.m.), and evening (5-8 p.m.) time periods. The model used was

$$\log (CO)_{ijk} = \mu + (LC)_i + T_j + \varepsilon_{ijk} \qquad (7)$$

where CO_{ijk} denotes the k^{th} observation in the i^{th} indoor location category during the j^{th} time period, μ is the general mean and ε_{ijk} is the random error of the $(ijk)^{th}$ observation. Time of day was found to have an insignificant effect (at a 5% probability level).

TABLE 15. SUMMARY STATISTICS: PERSONAL EXPOSURES IN PHOENIX

Microenvironment type	Category	n	CO concentration (ppm) Range	Arithmetic mean	Standard deviation
Indoor	All	380	0-17	2.0	2.3
	Restaurant	29	0-10	2.9	2.4
	Store	239	0-17	2.0	2.2
	Office	112	0-12	1.9	2.2
Commuting	All	844	0-50	6.4	5.5
	Bus	63	0-12	4.5	2.6
	Automobile	275	1-34	8.5	5.0
	Downtown driving	408	0-50	6.0	4.4
	Downtown walking	99	0-20	3.1	2.7
Residential driving		173	0-17	5.3	3.4

Effects of Location, Traffic Density, and Time of Day on Commuting Exposures--

To determine the effects of time, traffic density, and location on commuting exposures, the following model was used:

$$\log(CO)_{ijkm} = \mu + (LC)_i + T_j + (TR)_k + \varepsilon_{ijkm} \qquad (8)$$

where CO_{ijkm} denotes the m^{th} observation in the i^{th} location category during the j^{th} time period and k^{th} traffic density level, μ is the general mean and e_{ijkm} is the random error of the $(ijkm)^{th}$ observation. The results suggested that the exposures in automobile commuting were significantly higher (at a 5% probability level) than the other commuting exposures during the monitoring period of this study (Table 16).

TABLE 16. PHOENIX COMMUTING EXPOSURE GEOMETRIC MEANS BY LOCATION CATEGORY

Grouping*	Location category	n	Geometric mean (ppm)
A	Automobile	275	7.13
B	Downtown driving	406	4.75
C	Bus	63	3.57

*Means within a grouping are not significantly different.

Also, commuting exposures were significantly higher during heavy traffic levels and in the morning hours (Tables 17 and 18).

TABLE 17. PHOENIX COMMUTING EXPOSURE GEOMETRIC MEANS BY TRAFFIC DENSITY

Grouping*	Traffic density	n	Geometric mean (ppm)
A	Heavy	58	10.53
B	Average	589	5.11
C	Light	97	5.03

*Means within a grouping are not significantly different.

TABLE 18. PHOENIX COMMUTING EXPOSURE GEOMETRIC MEANS BY TIME OF DAY

Grouping*	Time of day	n	Geometric mean (ppm)
A	Morning	146	7.56
B	Evening	354	5.26
C	Afternoon	174	5.03
D	Midday	70	3.59

*Means within a grouping are not significantly different.

It is interesting to note that the commuting exposures recorded in the morning hours were higher than those recorded in the evening hours. In previous studies in Phoenix, CO levels have been highest in the evening due to atmospheric inversions that occur during the evening hours.

Effects of Traffic Density and Time of Day on Residential Driving Exposures--
Traffic density and time also had significant effects on residential driving exposures (Tables 19 and 20).

TABLE 19. PHOENIX RESIDENTIAL DRIVING EXPOSURE GEOMETRIC MEANS BY TRAFFIC DENSITY

Grouping*	Traffic density	n	Geometric mean (ppm)
A	Heavy	26	6.38
A B	Average	7	5.79
B	Light	134	3.79

*Means within a grouping are not significantly different.

TABLE 20. PHOENIX RESIDENTIAL DRIVING EXPOSURE GEOMETRIC MEANS BY TIME OF DAY

Grouping*		Time of day	n	Geometric mean (ppm)
A		Afternoon	26	6.38
A	B	Midday	7	5.79
	B	Evening	134	3.79

*Means within a grouping are not significantly different.

Comparison of Personal Exposures and Fixed-Site Concentrations--

To determine if linear relationships existed between the personal exposures and the fixed-site concentrations, each group of personal exposures was regressed upon the concentrations from the urban fixed site. Table 21 summarizes the results of this linear regression analysis. None of the linear relationships was found to be very strong based on the proportion of total sample variation explained by the linear regression fit (R^2 value) and the sample correlation coefficient, which provide empirical measure of linear association between the two types of measurements. The restaurant exposures had the best linear relationship with fixed-site concentrations. Any relationship that may exist between these two types of measurements is probably very complex and cannot be adequately described linearly.

TABLE 21. RESULTS OF LINEAR REGRESSION OF PHOENIX PERSONAL EXPOSURES ON FIXED-SITE CONCENTRATIONS

Exposure	Sample size	Intercept	Slope	Sample correlation coefficient	R^2
Restaurant	27	1.2	0.7	0.76	0.58
Office	102	0.6	0.7	0.69	0.48
Automobile driving	270	5.1	0.9	0.53	0.28
Bus commuting	62	2.2	0.7	0.45	0.21
Downtown walking	95	1.8	0.8	0.45	0.20
Downtown driving	404	3.5	0.6	0.43	0.18
Store	208	1.3	0.3	0.35	0.12

DENVER

Sampling Design

Technicians recorded indoor and commuting exposures in a section of downtown Denver surrounding a fixed monitoring station. Residential driving exposures were measured in a residential area surrounding another fixed monitor. The locations of the fixed sites and residential monitoring areas are shown on the map in Figure 17. The monitoring procedures are summarized below. The procedures are detailed further in a report by PEDCo (1981).

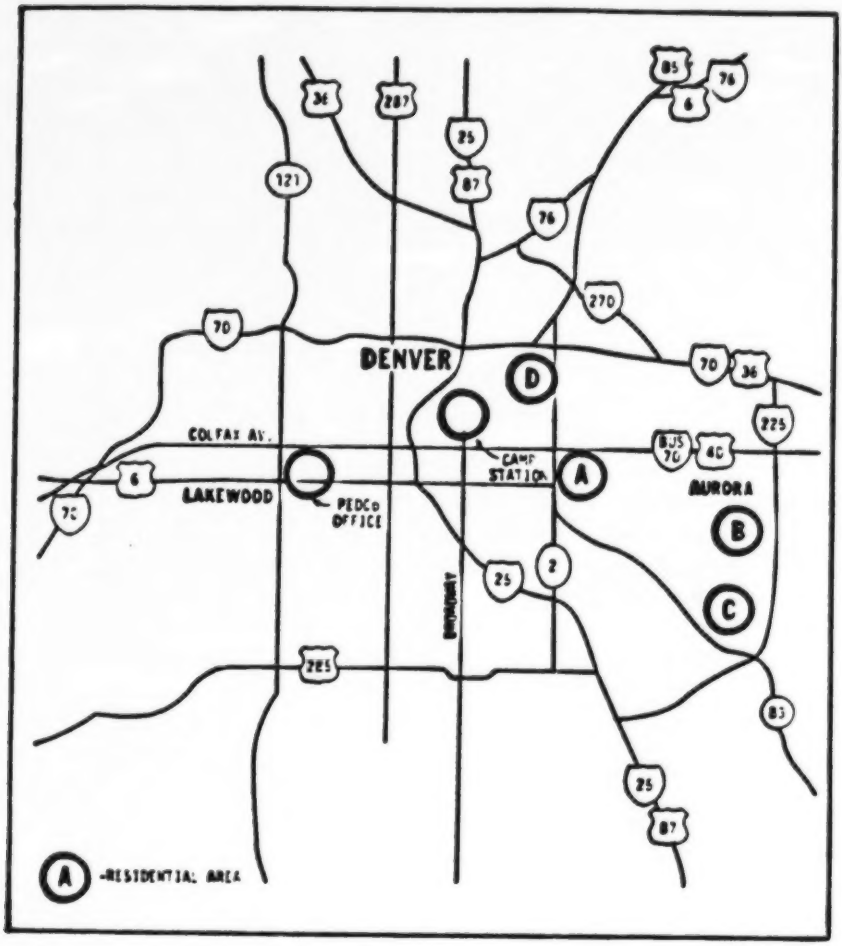

Figure 17. Residential driving exposure and fixed-site monitoring locations in Denver.

Personal Exposure Monitoring

Indoor--

A technician measured personal exposures in the immediate area of the urban monitoring station by carrying a personal monitor into restaurants, shops, offices, and public buildings where people are present throughout the day. A standard route was followed. At each location the integrated CO exposure was monitored for approximately 10 min. The choice of locations depended on the type(s) of buildings in the area, the distances between buildings, and whether sampling permission had been obtained. The morning and afternoon monitoring schedules were interchanged so that the time of day for sampling each location was random over the study period. The resulting data were categorized by location: restaurant, office, public building, or store.

Commuting--

Two technicians drove along major commuting routes to and from the urban area during peak traffic hours for half of the 8-wk monitoring period. For the other half of the monitoring period, one technician continued to drive, and the other rode buses along the same commuting routes. The routes were chosen to constitute approximately 30-min segments of driving or bus riding in a constant direction. Integrated CO exposures were recorded at 10-min intervals, conditions permitting, to represent the exposures of commuters using these routes. Commuting exposures were also recorded while waiting for buses and while driving and walking in the downtown area.

Residential Driving--

Technicians recorded CO concentrations while driving on lightly traveled residential streets during morning and afternoon hours. One technician performed this monitoring schedule in areas further than 1 mi from the fixed monitoring station. Data were obtained from inside the vehicle, which traveled at an average speed of approximately 30 mi/h. Integrated CO concentrations were collected at 10-min intervals during 30-min sampling periods corresponding to 15-mi segments in four residential areas. Both the morning and afternoon sampling sequences were randomized.

Fixed-Site Monitoring

Hourly CO averages were continuously recorded at two fixed sites. The "urban" site was an EPA Continuous Air Monitoring Program (CAMP) station equipped with a Beckman monitor. The "urban-residential" site was the contractor's own office; here a Bendix model 8501-5CA monitor was used.

Monitoring was also conducted at the manifold of the urban fixed-site monitor and inside that station.

Statistical Analyses

Summary Statistics--

Summary statistics for the personal exposures are shown in Table 22. Commuting exposures were approximately twice as high as residential driving exposures (arithmetic mean levels).

Effect of Time of Day on Indoor Exposures--

An analysis of variance was performed on the logarithmically transformed data to determine the effect of time of day on indoor exposures. The model used was similar to that described in Equation 7. The results showed that morning exposures were significantly higher (at a 5% probability level) than midday, evening, and afternoon exposure (Table 23).

Effect of Time of Day on Commuting Exposures--

Morning and evening commuting exposures were significantly higher; there was no significant difference between afternoon and midday exposures. These results are shown in Table 24.

TABLE 22. SUMMARY STATISTICS: PERSONAL EXPOSURES IN DENVER

Microenvironment type	Location category	n	CO Concentration (ppm) Range	Arithmetic mean	Standard deviation
Indoor	All	2069	0-58	6.1	4.5
	Restaurant	979	0-58	8.6	5.0
	Office	414	0-25	5.2	4.5
	Public bldg.	174	0-30	5.7	5.7
	Store	399	0-41	5.7	4.2
	Inside urban fixed station	103	0-17	5.5	3.1
Commuting	All	3836	0-55	10.7	7.4
	Bus	865	0-33	10.5	5.3
	Automobile	1046	0-55	13.6	9.7
	Downtown driving	1095	0-49	11.0	7.3
	Downtown walking	702	0-43	6.4	4.8
	Waiting for bus	128	1-32	8.7	6.0
Residential driving		610	0-45	6.1	4.9
At urban fixed station	Manifold of station	54	3-29	8.0	6.4

TABLE 23. DENVER INDOOR EXPOSURE GEOMETRIC MEANS BY TIME OF DAY

Grouping*	Time of day	n	Geometric mean (ppm)
A	Morning	614	6.8
B	Midday	771	4.5
C	Evening	51	2.9
D	Afternoon	633	2.5

*Means within a grouping are not significantly different.

TABLE 24. DENVER COMMUTING EXPOSURE GEOMETRIC MEANS BY TIME OF DAY

Grouping*	Time of day	n	Geometric Mean (ppm)
A	Morning	1430	8.7
A	Evening	719	8.5
B	Afternoon	899	7.1
B	Midday	698	6.9

*Means within a grouping are not significantly different.

Effect of Time of Day on Residential Driving Exposures--

Time of day had an insignificant effect on residential driving exposures (Table 25).

TABLE 25. DENVER RESIDENTIAL DRIVING EXPOSURE GEOMETRIC MEANS BY TIME OF DAY

Time of day	n	Geometric mean (ppm)
Morning	180	4.5
Midday	246	4.3
Afternoon	184	3.8

Comparison of Personal Exposures and Fixed-Site Concentrations--

To determine if linear relationships existed between the personal exposure and fixed-site concentrations, the data for each type of personal are displayed in Table 26. As would be expected, the personal exposures in close proximity to the fixed site had the strongest estimated linear relationships. This result is obtained by considering the proportion of the total sample variation explained by the least-squares regression fit (R^2 value) and the sample correlation coefficient. Personal exposures not in close proximity to the fixed site had the smallest R^2 values. Exposures related to indoor activities generally had larger R^2 values than those related to motor vehicles. However, one should view the results of this regression analysis with caution. As measured by the R^2 value, none of the linear relationships was very strong. Even the linear relationship for personal exposures inside the fixed station was poor ($R^2 = 0.37$). Clearly, any relationship that may exist between the two groups of measurements is very complex and cannot be adequately described by a simple linear relationship. Also, the fixed-site observations were hourly average concentrations, but the personal exposures were usually averaged over 10- to 15-min time periods. Thus, a large portion of any given hour was not observed in the personal exposure monitoring and the regression analysis estimates may be biased through the assumption that the personal exposures represent hourly averages. This problem may have been alleviated by the large number of samples in each regression, which should minimize the effects of the nonrepresentative personal exposures.

TABLE 26. RESULTS OF LINEAR REGRESSION OF DENVER PERSONAL EXPOSURES ON FIXED-SITE CONCENTRATIONS

Exposure	Sample size	Intercept	Slope	Sample correlation coefficient	R^2
Inside urban fixed station	99	1.7	1.0	0.61	0.37
Outside urban fixed station	51	2.6	1.0	0.60	0.35
Bus commuting	795	5.1	0.7	0.52	0.27
Office	378	1.7	0.7	0.43	0.19
Public building	167	3.1	0.6	0.43	0.18
Store	378	3.8	0.4	0.40	0.16
Restaurant	920	3.7	0.6	0.37	0.13
Downtown driving	1013	7.6	0.7	0.35	0.12
Downtown walking	654	4.5	0.4	0.24	0.06
Waiting for bus	115	6.4	0.3	0.22	0.05
Automobile commuting	998	10.4	0.4	0.15	0.02

SECTION 6

SUMMARY AND CONCLUSIONS

Recent studies have shown that CO concentrations are not homogeneous over large urban areas, and that demography, meteorological conditions, and activity each has a significant effect on human exposure to CO. In order to compare personal exposures with ambient concentrations that may not be indicative of population exposure, this study employed miniaturized personal exposure CO monitors to measure average concentrations at 10 to 30-min intervals in a large variety of urban, indoor, commuting, and residential locations in the vicinity of fixed monitoring stations in four major cities: Stamford, CT; Los Angeles, CA; Phoenix, AZ; and Denver, CO.

The findings of this study are summarized below:

- Except in Stamford, personal exposures during commuting and residential driving were higher than fixed-site ambient concentrations (arithmetic mean values).

- Except in Denver, indoor exposures were lower than fixed-site ambient concentrations (arithmetic mean values).

- The highest indoor exposures were found in Denver (arithmetic mean value of 6.1 ppm).

- The highest commuting and residential driving exposures were found in Los Angeles (arithmetic mean values of 16.4 ppm and 7.6 ppm, respectively).

- Hourly fixed-site arithmetic mean ambient concentrations in all four cities were highest in the morning (7 to 8 a.m.) and evening rush hours (4 to 6 p.m.). Except for a fixed monitoring station located near a construction site and busy intersection in Stamford, where peak levels were 10 to 12 ppm, morning and evening peak levels were approximately 6 ppm.

- In all four cities, regressing personal exposures on simultaneous fixed-site ambient concentrations resulted in inconclusive linear relationships. Any relationship that may exist between these two types of measurements is probably very complex and cannot be adequately described by a simple linear relationship.

- Exposures inside commercial locations on busy streets in all four cities were nonzero. This may be due to the diffusion into buildings of CO from vehicular emissions in the street or in attached parking structures.

- The highest estimated 8-h average exposure for a commuting office worker was found in Los Angeles (8.2 ppm).

- During 8-h fixed-site NAAQS exceedance time periods, at least 50% of the simultaneous indoor exposures were lower than the ambient concentrations (all four cities).

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APPENDIX A. FIXED-SITE MONITOR AUDIT RESULTS

Site	Analyzer Model and S/N	Audit Parameter and Range	Audit Conc. ppm	Analyzer Response ppm	Difference Analyzer-Audit ppm	Difference Analyzer-Audit Percent	Regression of Analyzer Response on Audit Concentration Y=mX + b Slope	Intercept	Correlation Coefficient	Performance
Ferguson Library Stamford CT (2-17-81)	Bendix 8501-5CA Bendix S/N 14897-S	Carbon Monoxide 0-50	44.5	43.0	-1.5	-3.4	0.967	-0.042	1.0000	E
			30.7	29.7	-1.0	-3.3				
			18.8	18.1	-0.7	-3.7				
			6.8	6.6	-0.2	-2.9				
			0.0	0.0	0.0	----				
Urban League Stamford CT (2-17-81)	Bendix 8501-5CA EPA 062777	Carbon Monoxide 0-50	44.0	44.2	+0.2	+0.5	0.998	-0.163	0.9998	E
			31.2	30.5	-0.7	-2.2				
			19.0	18.5	-0.5	-2.6				
			7.0	7.0	0.0	0.0				
			0.0	0.0	0.0	----				
Lakewood Denver CO (2-23-81)	Bendix 8501-5CA A062773	Carbon Monoxide 0-50	45.4	44.5	-0.9	-2.0	0.980	+0.052	1.0000	E
			29.3	28.8	-0.5	-1.7				
			16.6	16.4	-0.2	-1.2				
			7.1	7.0	-0.1	-1.4				
			0.0	0.0	0.0	----				
CAMP Denver CO (2-24-81)	Beckman 866 Beckman S/N 108	Carbon Monoxide 0-50	42.9	38.5	-4.4	-10.3	0.857	+1.242	0.9994	S
			28.9	25.7	-3.2	-11.1				
			17.3	15.5	-1.8	-10.4				
			7.1	7.2	+1.0	+1.4				
			0.0	1.8	+1.8	----				
Cardiff St. L.A. CA (2-25-81	Interscan 1146 Interscan S/N 22249	Carbon Monoxide 0-50	42.3	34.0	-8.3	-19.6	0.800	+0.161	0.9999	U
			28.7	23.0	-5.7	-19.9				
			17.5	14.2	-3.3	-18.9				
			7.3	6.2	-1.1	-15.1				
			0.0	0.0	0.0	----				
Sta. 86 L.A.,CA (2-26-81	Bendix 8501-5CA SN SCAQMD 2811	Carbon Monoxide 0-50	42.4	43.0	+0.6	+1.4	1.012	+0.207	0.9999	E
			28.8	29.4	+0.6	+2.1				
			17.3	17.9	+0.6	+3.5				
			7.4	7.8	+0.4	+5.4				
			0.0	0.0	0.0	-----				
Central Phoenix, AZ (3-2-81)	Beckman 866 Maricopa S/N F02928	Carbon Monoxide 0-50	42.7	40.8	-1.9	-4.4	0.957	-0.257	0.9999	E
			29.1	27.2	-1.9	-6.5				
			17.5	16.8	-0.7	-4.0				
			7.4	6.7	-0.7	-9.5				
			0.0	-0.2	-0.2	----				
24th & Roosevelt Phoenix, AZ (3-3-81)	Bendix 8501-CA EPA 062774	Carbon Monoxide 0-50	42.3	41.0	-1.3	-3.1	0.961	+0.349	1.0000	E
			29.3	28.5	-0.8	-2.7				
			17.8	17.5	-0.3	-1.7				
			7.4	7.5	+0.1	+1.4				
			0.0	0.3	+0.3	-----				

E = Excellent S = Satisfactory U = Unsatisfactory

APPENDIX B. PERSONAL MONITOR AUDIT RESULTS*

Site	Analyzer Model and S/N	Audit Parameter and Range	Audit Conc. ppm	Analyzer Response ppm	Avg. LCD RDG.	Integrator response	Integration Time, min	Difference Analyzer-Audit ppm	Difference Analyzer-Audit Percent	Regression of Analyzer Response on Audit Concentration Y=mX + b Slope	Intercept	Correlation Coefficient	Performance
Urban League, Stamford CT (2-17-81	GE 15EC S3003 EPA 179772	Carbon Monoxide 0-50	44.1	43.8	043	1315	30	-0.3	-0.6	0.994	+0.021	1.000	E
			30.7	30.6	030	306	10	-0.1	-0.3				
			0.0	0.0	000	15	20	0.0	----				
			18.6	18.0	018		*	-0.6	-3.2				
			6.5	6.0	006		*	-0.5	-7.7				
	GE 15EC S3003 EPA 179773	Carbon Monoxide 0-50	44.1	44.7	044	1341	30	+0.6	+1.4	1.013	-0.023	1.0000	E
			30.7	31.0	030	310	10	+0.3	+1.0				
			0.0	0.0	-000	000	20	0.0	----				
			18.6	18.0	018		*	0.6	-3.2				
			6.5	6.0	006		*	-0.5	-7.7				
Lakewood Denver, CO (2-23-81	GE 15EC S3003 EPA 179705	Carbon Monoxide 0-50	45.4	47.3	045	946	20	+1.9	+4.2	1.036	+0.309	1.0000	E
			16.6	17.6	016	176	10	+1.0	+6.0				
			7.1	7.6	007	076	10	+0.5	+7.0				
			0.0	0.3	-000	007	20	+0.3	----				
			29.3	28.75	28.75		*	-0.55	-1.9				
	GE 15EC S3003 EPA 179770	Carbon Monoxide 0-50	45.4	46.6	045	933	20	+1.2	+2.6	1.000	+1.200	1.0000	E
			16.6	17.8	016	178	10	+1.2	+7.2				
			7.1	8.3	006.5	83	10	+1.2	+16.9				
			0.0	1.2	-000	24	20	+1.2	----				
			29.3	29.0	029		*	-0.3	+1.0				
Cardiff St. Los Ange CA (2-25-81	GE 15EC S3003 SAI 120	Carbon Monoxide 0-50	42.3	40.6	042	852	21	-1.7	-4.0	0.937	+0.664	0.9995	S
			17.5	16.5	016.5	165	10	-1.0	-5.7				
			7.3	7.2	006.5	72	10	-0.1	-1.4				
			0.0	1.2	-001	25	20	+1.2	----				
			28.7	28.5	028.5		*	-0.2	-0.7				
	GE 15EC S3003 SAI 04	Carbon Monoxide 0-50	42.3	37.6	040	789	21	-4.7	-11.1	0.849	+1.501	0.9998	U
			17.5	16.0	016.5	160	10	-1.5	-8.6				
			7.3	7.6	006.5	76	10	+0.3	+4.1				
			0.0	1.8	-000	36	20	+1.8	----				
			28.7	27.5	027.5		*	-1.2	-4.2				
5730 N. 4th St Phoenix, AZ (3-2-81)	GE 15EC S3003 EPA 179703	Carbon Monoxide 0-50	42.8	38.3	039	766	20	-4.5	-10.5	0.903	-0.507	0.9997	S
			17.5	15.1	015.5	151	10	-2.4	-13.7				
			7.4	5.7	006	57	10	-1.7	-23.0				
			0.0	0.0	-000	000	20	0.0	-----				
			29.3	26.0	026		*	-3.3	-11.3				
24th and Roosevelt Phoenix, AZ (3-3-81)	GE 15EC S3003 EPA 179704	Carbon Monoxide 0-50	42.3	39.9	040	797	20	-2.4	-5.7	0.940	+0.145	0.9999	S
			17.8	16.8	016.5	168	10	-1.0	-5.6				
			7.4	7.2	007	72	10	-0.2	-2.7				
			0.0	0.1	-000	2	20	+1.0	----				
			29.3	28.0	028		*	-1.3	-4.5				
	GE 15EC S3003 EPA 179702	Carbon Monoxide 0-50	42.3	41.2	042	823	20	-1.1	-2.6	0.928	+2.132	0.9996	U
			17.8	18.9	019	189	10	+1.1	+6.2				
			7.4	9.6	010	96	10	+2.2	+30.0				
			0.0	1.5	001.5	30	20	+1.5	----				
			29.3	30.0	030		*	+0.7	+2.4				

*Instantaneous readings - data taken from liquid crystal display as soon as stable. Instantaneous readings were not used in computing regressions or in evaluation.

E = Excellent S = Satisfactory U = Unsatisfactory

APPENDIX C. FREQUENCY DISTRIBUTIONS OF EXPOSURES AND FIXED-SITE DATA

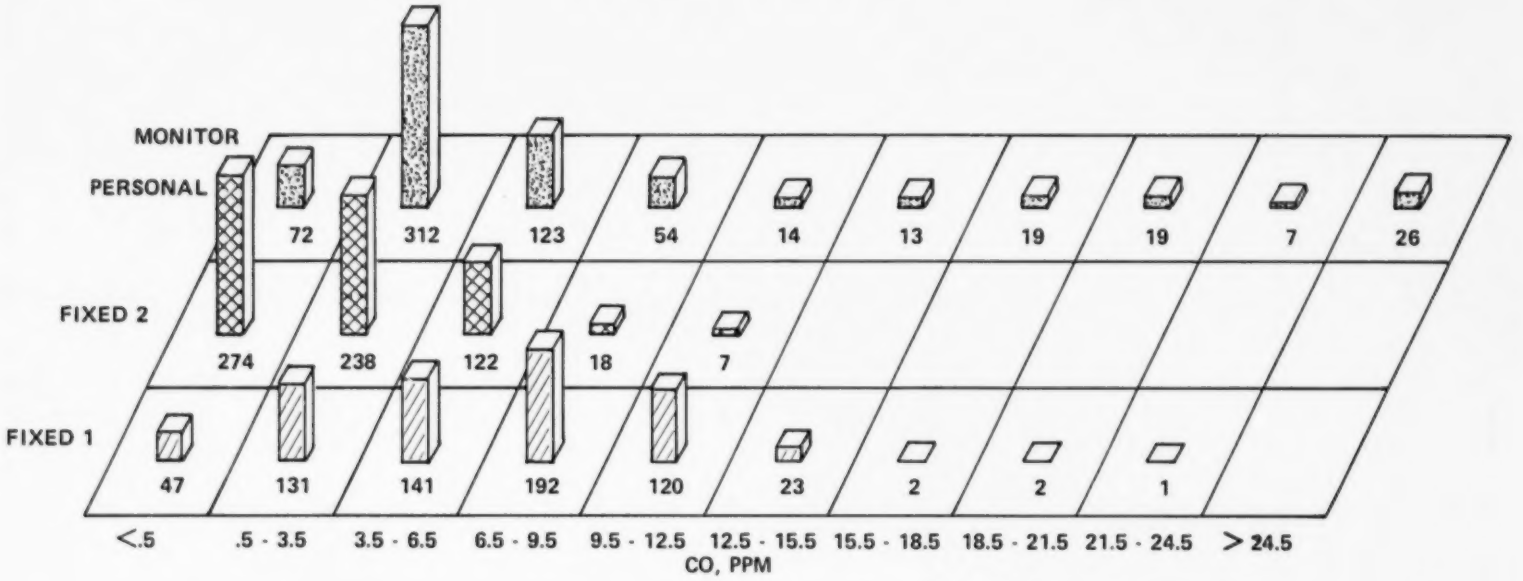

Figure C-1. Frequency distribution of indoor exposures and fixed-site concentrations in Stamford.

APPENDIX C. FREQUENCY DISTRIBUTIONS OF EXPOSURES AND FIXED-SITE DATA
(continued)

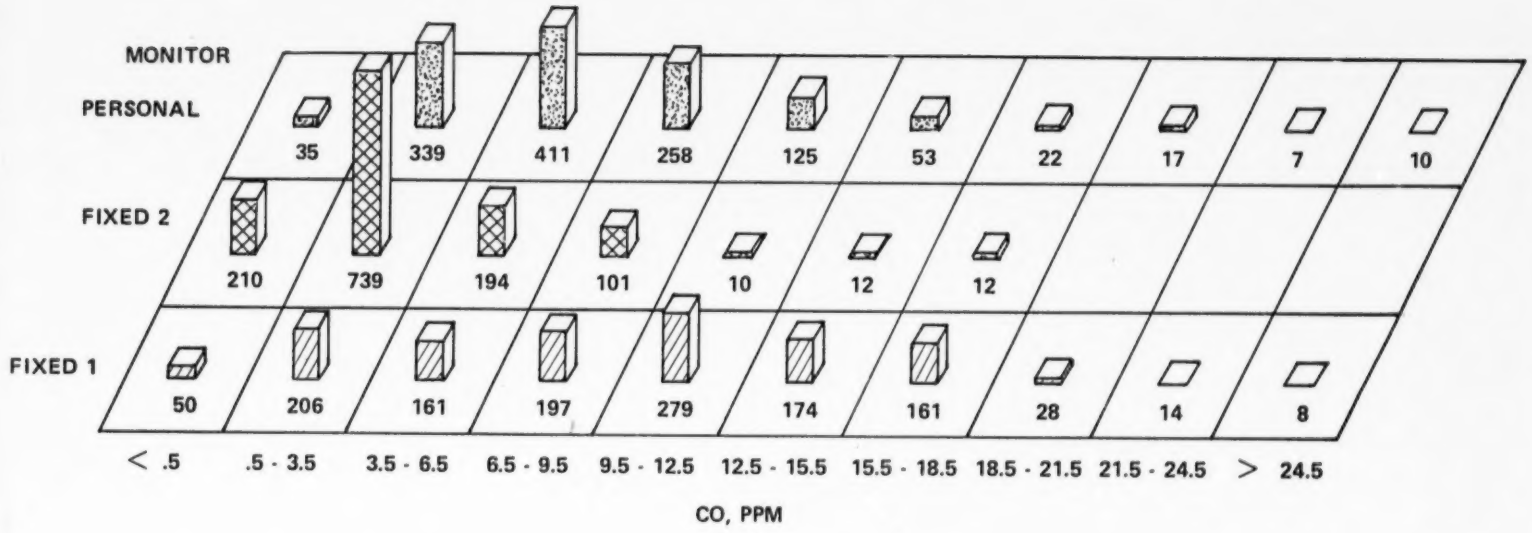

Figure C-2. Frequency distribution of commuting exposures and fixed-site concentrations in Stamford.

APPENDIX C. FREQUENCY DISTRIBUTIONS OF EXPOSURES AND FIXED-SITE DATA
(continued)

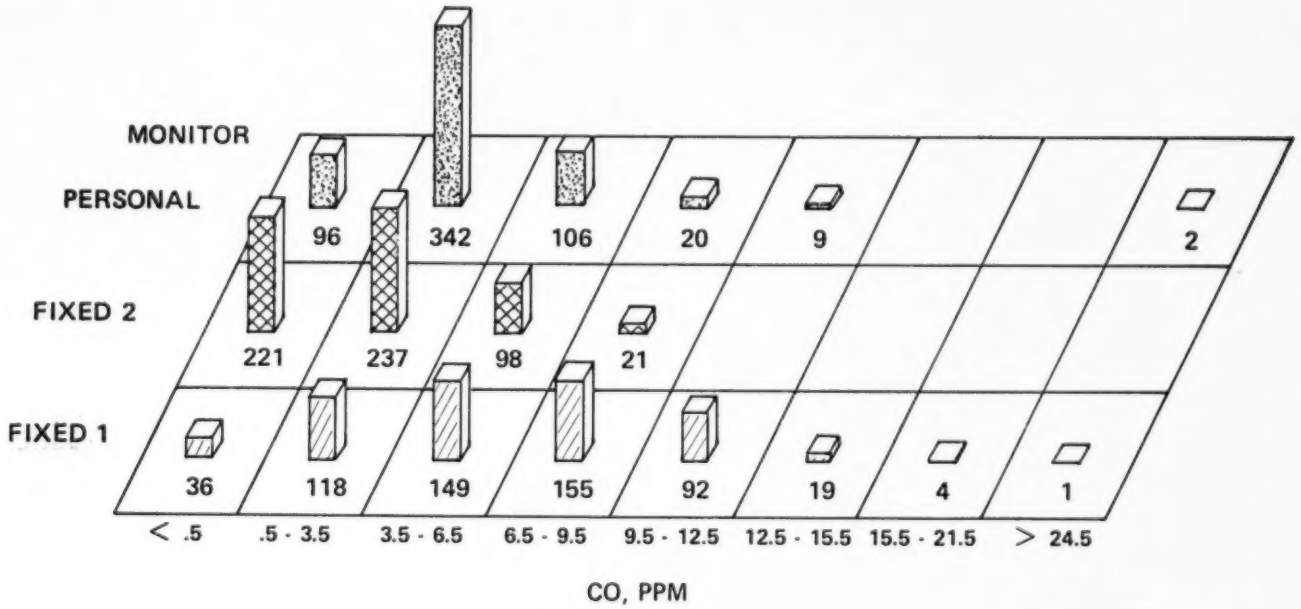

Figure C-3. Frequency distribution of residential driving exposures and fixed-site concentrations in Stamford.

APPENDIX C. FREQUENCY DISTRIBUTIONS OF EXPOSURES AND FIXED-SITE DATA
(continued)

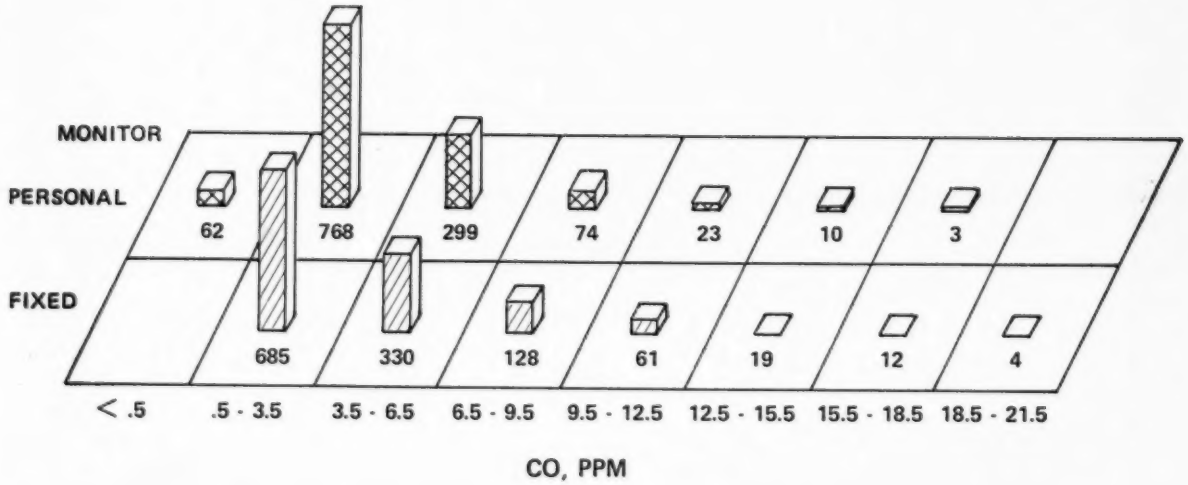

Figure C-4. Frequency distribution of indoor exposures and fixed-site concentrations in Los Angeles.

APPENDIX C. FREQUENCY DISTRIBUTIONS OF EXPOSURES AND FIXED-SITE DATA
(continued)

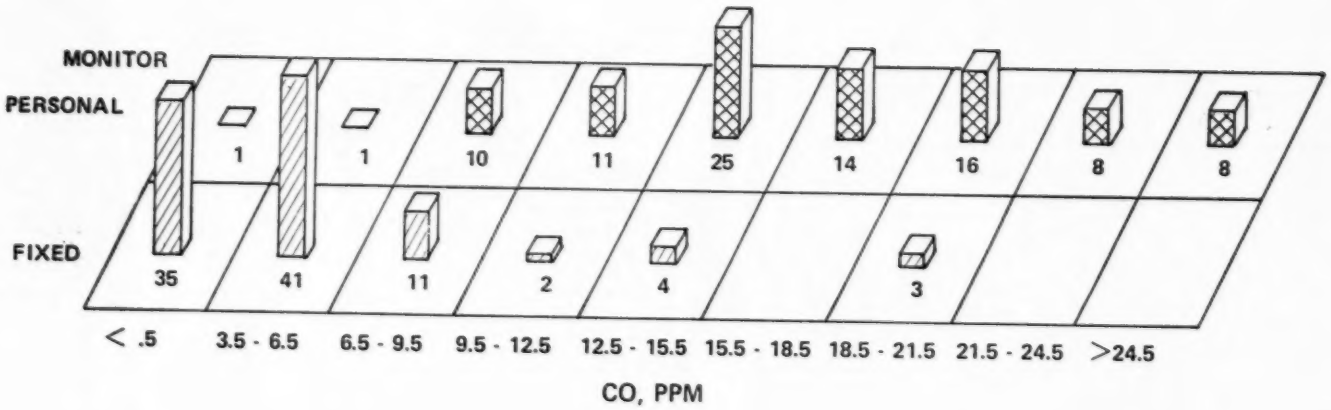

Figure C-5. Frequency distribution of commuting exposures and fixed-site concentrations in Los Angeles.

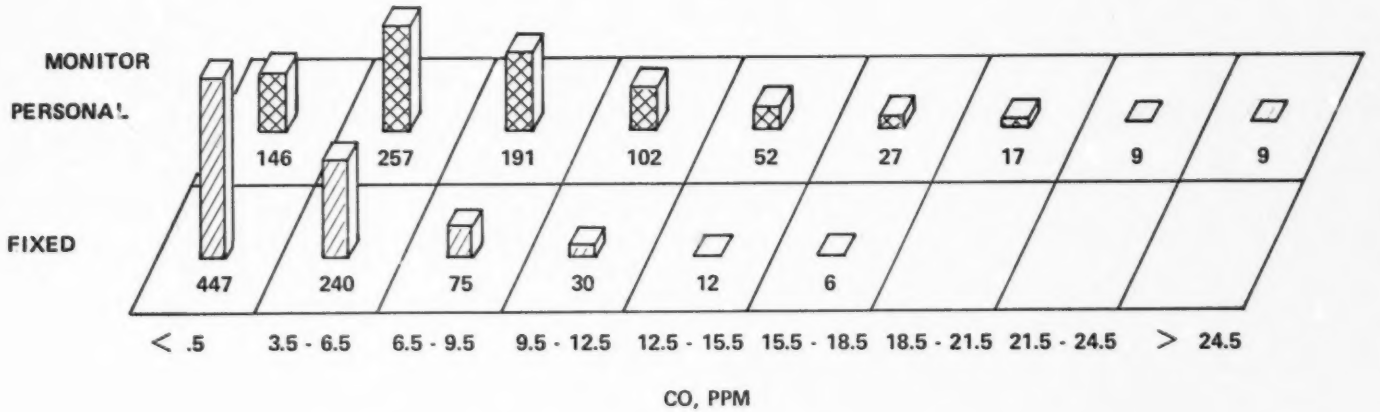

Figure C-6. Frequency distribution of residential driving exposures and fixed-site concentrations in Los Angeles.

APPENDIX C. FREQUENCY DISTRIBUTIONS OF EXPOSURES AND FIXED-SITE DATA (continued)

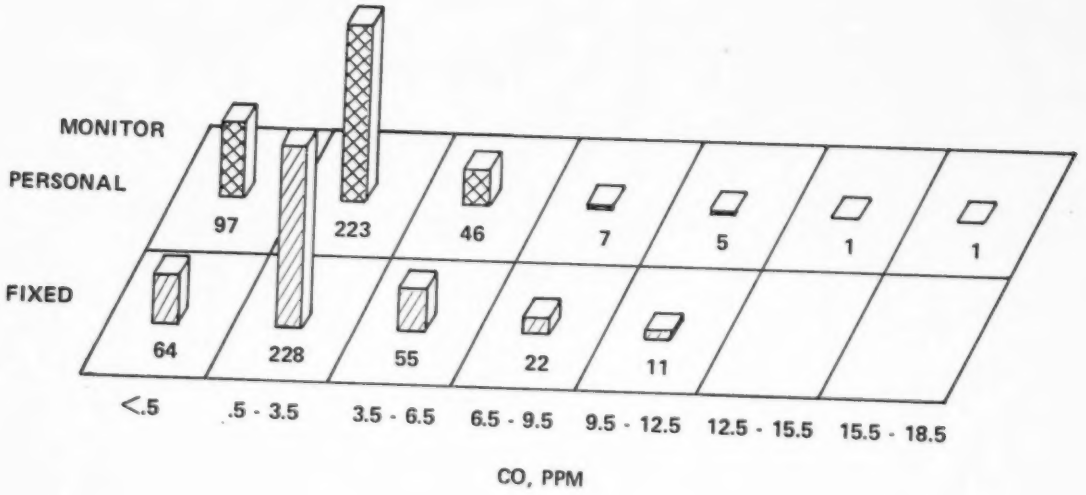

Figure C-7 Frequency distribution of indoor exposures and fixed-site concentrations in Phoenix.

APPENDIX C. FREQUENCY DISTRIBUTIONS OF EXPOSURES AND FIXED-SITE DATA
(continued)

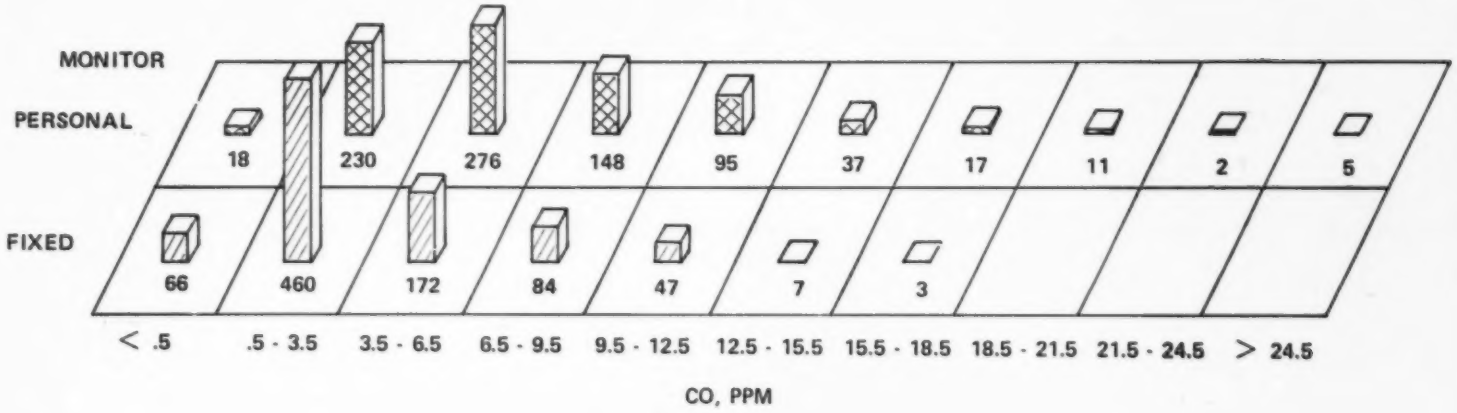

Figure C-8. Frequency distribution of commuting exposures and fixed-site concentrations Phoenix.

APPENDIX C. FREQUENCY DISTRIBUTIONS OF EXPOSURES AND FIXED-SITE DATA (continued)

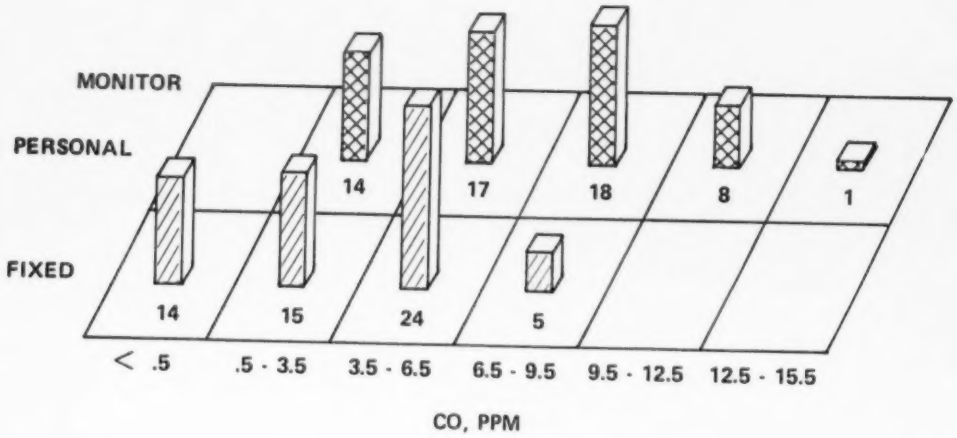

Figure C-9. Frequency distribution of residential driving exposures and fixed-site concentrations in Phoenix.

APPENDIX C. FREQUENCY DISTRIBUTIONS OF EXPOSURES AND FIXED-SITE DATA
(continued)

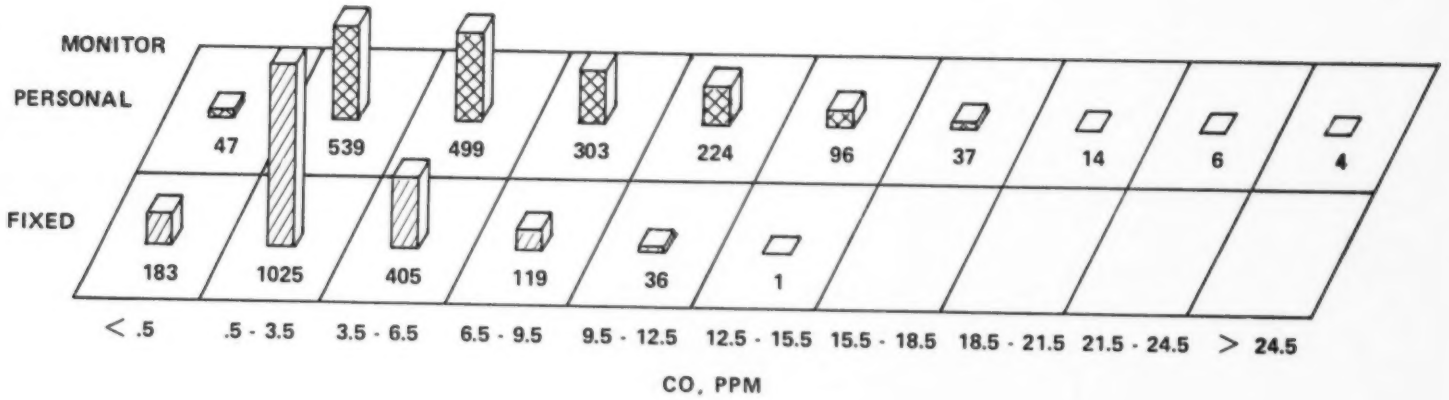

Figure C-10. Frequency distribution of indoor exposures and fixed-site concentrations in Denver.

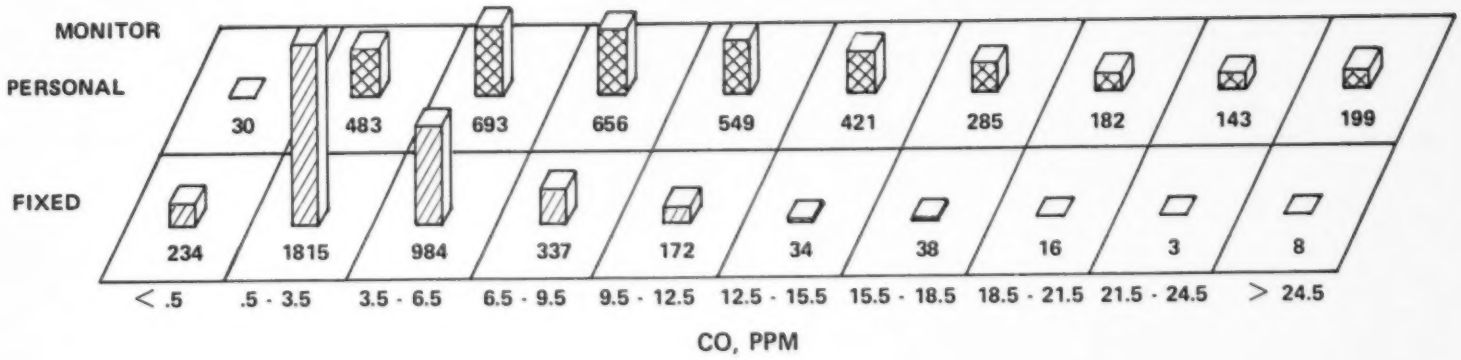

Figure C-11. Frequency distribution of commuting exposures and fixed-site concentrations in Denver.

APPENDIX C. FREQUENCY DISTRIBUTIONS OF EXPOSURES AND FIXED-SITE DATA
(continued)

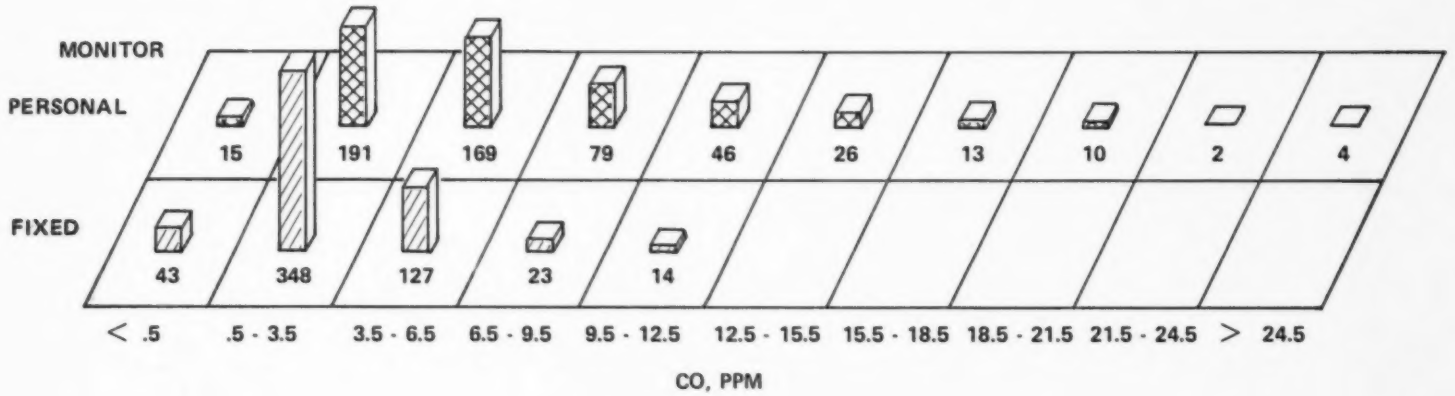

Figure C-12. Frequency distribution of residential driving exposures and fixed-site concentrations in Denver.